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Sports medicine and physical rehabilitation, volume II

Edited by
Michael Jaffe, David Levine and Denis J. Marcellin-Little

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Sports medicine and physical rehabilitation, volume II

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Editorial: Sports medicine and physical rehabilitation, volume II

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Editorial on the Research Topic
Sports medicine and physical rehabilitation, volume II

Interest in Veterinary Sports Medicine and Physical Rehabilitation is continuing to grow. Articles within the 1st volume of the eBook focused on Veterinary Sports Medicine and Physical Rehabilitation published by Frontiers in Veterinary Science have been viewed more than 95,000 times. Continued research and clinical care in the field of veterinary rehabilitation has expanded our knowledge in several areas. As with all research, discovery prompts new questions and helps deepen the knowledge in the field to enhance the care for our veterinary patients. This Research Topic issue addresses several new questions that authors tackled through articles ranging from case reports, reviews, and original research. The 2nd volume of the eBook includes 18 new articles by 74 authors focused on a variety of topics. We are confident that readers will find these articles clinically useful as well as thought-provoking.

In the current eBook, several articles examine the physiologic impact of exercise on sporting and working dogs. Each article poses questions that will enlighten readers about the physiologic effects and the physical risks of training and performing their activities. Markley et al. approached training issues of dogs competing in agility through an internet survey. The article described factors contributing to injuries that occur during the course of training and competition, including training to jump before skeletal maturity. Their findings may serve to guide trainers in selecting appropriate activities for dogs of all ages. Similar methods have been used by Sundby et al. through an internet survey to further enhance our knowledge of demographic risk factors for injury in canine athletes, while Fry et al. investigated factors influencing the incidence of injuries to the iliopsoas muscle. Iliopsoas injury is often challenging to diagnose and manage. Their research gives us guidelines for the chronic impact that this injury causes and provides information that will guide clinicians managing that problem.

Several other articles in the current eBook focus on factors affecting working and sporting dogs. Pogue et al. investigated the effects of jump height on forelimb landing forces in Border Collies that compete in agility competitions. Jumping is known to increase the risk of carpi and forepaw injury. No difference was found when comparing kinematics and peak forces resisted by forelimbs during standard jumps and jumps with reduced height. This information opens the door for further investigation of the causes and effects of forelimb injuries during jumping. Essner et al. described training methods in Swedish sporting and working dogs. The article highlights the effects of physical exposure and management routines and provides insight about appropriate warm-up routines before activity. The article by Lenfest et al. examined the relationship of serum thyroid concentrations in sled dogs retired from their sport. Sled dogs often have a low baseline thyroid concentration. Once retired, these dogs continue to maintain a lower than standard reference range value to their thyroid concentration. This paper should help guide clinicians in their decision-making for these patients with respect to diagnosis and potential treatment for hypothyroidism.

Rehabilitation medicine practices often treat patients recovering from thoracolumbar intervertebral disc herniation. Amaral Marrero et al. investigated the effect of thoracolumbar intervertebral disc extrusion surgery on static body weight distribution during the recovery period following surgery. They also evaluated the impact of intervertebral disc disease on muscle atrophy by quantifying girth measurements. Dogs with intervertebral disc disease shifted weight forward early after surgery. While that cranial weight shift decreased over the 3 months that followed surgery, the cranial weight shift remained at the end of the study. In another 12-week-long study evaluating dogs with myelopathies, Sedlacek et al. evaluated the benefits of physical rehabilitation in dachshunds with mild or moderate myelopathy of the T3-L3 vertebral column segment. Most dogs did well and only one dog in nine had a recurrence of myelopathy within 2 years. In a pilot study, Lewis et al. described sensory-enhanced rehabilitation for patients with spinal cord injury. The study expanded our knowledge in that area of physical rehabilitation and offers opportunities to further investigate the effects of flooring and sensory stimulation on the recovery of neurologically-compromised dogs.

Osteoarthritis is a ubiquitous problem in dogs. Managing patients with osteoarthritis in practice remains very challenging. Physical rehabilitation and regenerative therapy are components of the multimodal management of canine osteoarthritis. The canine osteoarthritis staging tool (COAST) has been proposed to guide veterinarians and pet owners when diagnosing of osteoarthritis in its early stages. Mosley et al. proposed a consensus statement for Canadian veterinarians that is based on stages 1–4 of the COAST. The information will assist clinicians when they develop therapeutic plans for dogs with osteoarthritis. Kim et al. reported the result of an exploratory, double blinded, randomized, prospective clinical trial that compared the effects of allogeneic mesenchymal stem cell injection and to high-molecular-weight hyaluronic acid in dogs with osteoarthritis. Hyaluronic acid was more effective than stem cell injection in that study.

Muscle injuries are common injuries managed in physical rehabilitation and sports medicine. Their diagnosis can be challenging. This eBook includes a study in the horse that evaluated multifidus muscle function during exercise. Ursini et al. used electromyography to investigate the multifidus m. as a sentinel muscle which has been noted to atrophy due to chronic limb dysfunction. By measuring electromyographic changes in the multifidus muscle during a variety of therapeutic exercises, incorporating ground poles during exercise was effective in activating the multifidus muscle.

In a case report describing the management of infraspinatus and supraspinatus tendinopathy in two dogs, Owen documented tendon healing in dogs being managed using piezoelectric shockwave therapy. The paper adds to our knowledge regarding the use of shockwave therapy to manage tendon injuries in the dog shoulder. Weber et al. examined muscular activity in the forelimbs of retrievers carrying varying weights in their mouths while trotting. By evaluating dogs trotting across a pressure-sensitive walkway, they learned that the amount of pressure placed on the forelimbs increases when carrying heavier weights. The contraction time of the deltoideus muscle increased but contraction time in the biceps brachii muscle did not increase. This novel investigative approach to the bicipital tenopathy was informative and open the doors to future research.

Beyond these articles, several other articles provided original important information pertinent to physical rehabilitation: Frye et al. investigated strategies required to develop a treatment plan to provide physical rehabilitation to geriatric dogs, Rosen et al. prospectively evaluated complications in patients using orthoses or exoprostheses, Gundersen et al. reported a stifle function score and compared its association with ground reaction forces in dogs with cranial cruciate ligament rupture., and Bieber et al. measured ground reaction forces in dogs wearing protective footwear during training and exercise.

This second eBook volume on Sports Medicine and Physical Rehabilitation will be a valuable resource for rehabilitation and sports medicine clinicians. The Editors are extremely pleased with the strength and diversity of the 18 excellent articles included in this volume which will lay the groundwork for future studies and pose new questions in the field.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Internet Survey of Risk Factors Associated With Training and Competition in Dogs Competing in Agility Competitions

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Objective: To describe risk factors associated with training and competition in relation to frequency and severity of injuries experienced by agility dogs.

Procedures: An internet-based survey collected data on competition level variables and training level variables. The primary outcome was history of any injury and a secondary outcome considered history of severe injury (injury lasting > 3 months). Logistic regression was used to estimate associations and final models were obtained *via* backward selection to identify the strongest associations within variables.

Results: There were 4,197 dogs included in this analysis. Injury was reported for 1,737 (41.4%) dogs and severe injury was reported for 629 (15.0%). In the model with competition level factors, jumping 4" (OR: 1.50) or 2–4" (OR: 1.31) over shoulder height compared to jumping 0–2" lower and competing at national events was associated with increased injury risk, while competing 6+ times on rubber matting was associated with lower risk (OR: 0.62). Training level variables associated with injury risk were age starting jump, teeter, and weave training, with the highest risk observed for dogs starting jump training between 3 and 18 months but starting weave and teeter training after 18 months of age.

Conclusion and Clinical Relevance: Many variables thought to be associated with injury risk were not significant in the final model. Starting jump training at an earlier age was associated with greater risk of injury relative to starting after 18 months. It is possible that the high impact of jump training before skeletal maturity may increase the risk of injuries or musculoskeletal conditions. The increased risk of injury in dogs that jump 2–4, or 4+ inches higher than shoulder height may be due to increased biomechanical forces during takeoff and landing. Faster dogs may be at higher risk of injury; handlers planning competition around big events or competing at the national level are likely to have faster dogs, and may be less likely to compete on rubber matting. These data provide valuable current insight into the possible effects that training and competition variables may have on injury risk in agility dogs.

Keywords: agility, canine, sports medicine, injury, training, competition

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INTRODUCTION

Dog agility is a popular performance event that has grown rapidly in the past decade. Entries for American Kennel Club agility events have increased by 38% over the last decade.[1] As the popularity of agility has increased, reported injury rates have also increased from 32% in 2009 to 41.7% in 2019 (1). The cause of the increased injury rate is likely multifactorial (1). Risk factors associated specifically with training and competition have been minimally evaluated. A previous study, performed by Cullen et al., used multivariable techniques to evaluate some potential risk factors for agility injuries (2). Data collected in this study only found the use of alternative therapeutic treatments to be associated with higher odds of injury (2).

In racehorses, the training and competition level risk factors for catastrophic musculoskeletal injury have been thoroughly investigated. Factors such as age at first start, higher race class, surface condition (firmer turf or wetter conditions on dirt), longer race distance, greater number of starts, longer career length, and previous injury have all been consistently shown to increase risk of catastrophic musculoskeletal injury in racehorses (3). The literature evaluating competition and training risk factors in human athletics is extensive and risk factors vary significantly by sport (4–10). Many similar training and competition variables exist in canine agility but have not been previously evaluated in relation to injury risk. At this time, there is no published data regarding the effect of variables such as jump height, level of competition, age at which training and competition was started, surface condition, and a variety of other factors that may play a role in increasing or decreasing injury risk.

While the obstacles that comprise agility courses have, for the most part, stayed the same over the past decade, the technicality of course design has increased (11, 12). This has resulted in changes to both handling and training techniques. There are a variety of ways of training each of the obstacles and as course speeds have increased there are trends in training obstacles to increase speed. However, risk of injury associated with types of training techniques or age at time of training certain techniques has not been evaluated.

The aim of this study was to thoroughly evaluate variables in canine agility training and competition that may affect the prevalence and severity of injuries agility dogs sustain. We wanted to specifically evaluate training-specific and competition-level factors that might be associated with injury history and describe the association between them and injury history. We hypothesized that early jump training, jumping higher jump heights, stopped contact training, and increasing number of trial weekends per year or runs per day would be associated with increased injury risk. We also hypothesized that planned time off would be associated with decreased injury risk.

[1]Personal communication. Carrie DeYoung, Director of AKC Agility. June 30, 2020.

MATERIALS AND METHODS

The internet-based survey utilized has been described previously (1). In brief, the survey was conducted in English and was distributed primarily *via* social media during a 6-week period in the fall of 2019 with University Institutional Review Board approval.[2,3,4] Eligible dogs had competed in at least one agility competition in the preceding 3 years. We classified our major variables of interest as "demographic variables" (both handler and dog), "competition variables" (e.g., primary competition venue, competition surface), and "training variables" (e.g., age at which agility training started, and methods for training different obstacles).

Competition level variables examined were: jumping height difference (jump height – height at the withers), primary organization, highest level achieved, number of trial weekends per year, number of days competing per trial weekend, number of runs per day, number of times the dog had competed at the national level, and number of times the dog had competed at the international level. Also examined was the frequency of competing on various surfaces. Surfaces included grass, sand, dirt, turf, rubber, foam, and other. Handlers were asked how they planned their training and competition schedules – around a big event, around availability of trials/schedule, a mix of the two, or other.

Training level variables were reported age starting any agility training, age starting each specific agility obstacle, age competing in first trial, age competing in first fun match, the behavior the dog performs at the end of each contact obstacle, and the method for training the weave obstacle. Contact obstacles are defined as having a "contact zone" where the dog must touch any part of one foot prior to exiting the obstacle for the A-frame and dogwalk, and where the dog must touch the "up" contact zone when ascending and then "down" contact zone one the plank touches the ground for the teeter obstacle. For the purpose of this study the contact obstacles evaluated for training techniques included the A-frame, teeter, dogwalk and weave obstacles. The training techniques evaluated for the A-frame and dogwalk were: (1) 2-on 2-off, defined as stopping with the front two feet on the ground and the rear two feet in the contact zone of the obstacle; (2) All 4 on, defined as stopping with all 4 paws in the contact zone; (3) Running, defined as moving up and over the obstacle without stopping; and (4) Other. The training techniques evaluated for the teeter were: (1) 2-on 2-off; (2) All 4 on in a down position; (3) All 4 on in a standing position; (4) Other specific trained behavior; and (5) No specific trained behavior. Weave obstacle training techniques included: (1) 2 × 2, defined as starting with a single set of 2 weave poles and systematically adding 2 poles; (2) Channel method, defined as where the weave poles are offset so that a "channel" is formed between the two lines of poles and eventually the channel is closed so that the dog learns the weaving motion; (3) Guide wires, defined as where the weave poles are set

[2]Qualtrics survey software, Provo UT.
[3]Copies of the questionnaire are available from the corresponding author on request.
[4]Facebook.

TABLE 1 | Age adjusted associations between competition risk factors and injury history.

	N (%)	Any injury OR (95% CI)	Any injury *p*-value	Severe injury OR (95% CI)	Severe injury *p*-value
Primary organization			<0.001[a]		0.56
AKC	1,172 (27.9)	REFERENCE		REFERENCE	
CPE	344 (8.2)	0.79 (0.61, 1.01)		0.89 (0.64, 1.26)	
USDAA	296 (7.1)	1.37 (1.05, 1.78)		1.11 (0.79, 1.58)	
NADAC	112 (2.7)	0.88 (0.58, 1.33)		1.10 (0.65, 1.88)	
AAC (Canada)	225 (5.4)	1.06 (0.79, 1.42)		0.69 (0.44, 1.08)	
Other North American	813 (19.4)	0.84 (0.70, 1.02)		0.99 (0.76, 1.27)	
FCI agility	756 (18.0)	1.40 (1.16, 1.69)		0.96 (0.74, 1.26)	
Other non-North American	477 (11.4)	1.26 (1.01, 1.58)		1.17 (0.87, 1.58)	
Highest level achieved			0.013[a]		0.39
Entry level	596 (14.2)	0.74 (0.60, 0.91)		0.82 (0.60, 1.13)	
Intermediate level	766 (18.3)	1.00 (0.84, 1.19)		1.05 (0.83, 1.33)	
High level	2,829 (67.5)	REFERENCE		REFERENCE	
Jump height difference			<0.001[a]		0.090[a]
Jumping > 4” above height	144 (3.5)	1.70 (1.19, 2.43)		1.22 (0.76, 1.95)	
Jumping 2–4” above height	299 (7.3)	1.47 (1.13, 1.91)		1.11 (0.77, 1.59)	
Jumping 0–2” above height	853 (20.9)	1.05 (0.87, 1.26)		0.91 (0.70, 1.18)	
Jumping 0–2” below height	1,158 (28.4)	REFERENCE		REFERENCE	
Jumping 2–4” below height	797 (19.6)	0.74 (0.61, 0.90)		0.72 (0.55, 0.95)	
Jumping 4–6” below height	485 (11.9)	0.91 (0.73, 1.14)		0.87 (0.65, 1.17)	
Jumping > 6” below height	339 (8.3)	0.95 (0.74, 1.22)		1.14 (0.83, 1.56)	
Approach to competition planning			<0.001[a]		<0.001[a]
Plan around availability/schedule	2,801 (67.0)	REFERENCE		REFERENCE	
Plan around a big event	101 (2.4)	1.61 (1.07, 2.42)		1.93 (1.18, 3.17)	
Mix of the two	1,107 (26.5)	1.50 (1.30, 1.73)		1.32 (1.08, 1.60)	
Other approach	171 (4.1)	0.89 (0.64, 1.24)		1.36 (0.91, 2.05)	
Advance competition planning			0.078[a]		0.051[a]
1–2 months	1,533 (36.7)	REFERENCE		REFERENCE	
3–6 months	1,910 (45.7)	1.15 (1.00, 1.32)		1.17 (0.96, 1.43)	
6–12 months	631 (15.1)	1.25 (1.03, 1.52)		1.42 (1.10, 1.83)	
12+ months	104 (2.5)	0.97 (0.64, 1.47)		0.94 (0.52, 1.70)	
Trial weekends per year			0.002[a]		0.050[a]
<5 weekends	448 (10.7)	0.79 (0.58, 1.07)		1.82 (1.16, 2.86)	
5–10 weekends	918 (21.9)	0.95 (0.73, 1.25)		1.54 (1.02, 2.34)	
11–15 weekends	1,082 (25.8)	1.12 (0.86, 1.46)		1.62 (1.08, 2.43)	
16–20 weekends	906 (21.6)	1.25 (0.95, 1.64)		1.92 (1.28, 2.89)	
21–25 weekends	530 (12.7)	1.18 (0.88, 1.58)		1.58 (1.02, 2.46)	
26+ weekends	304 (7.3)	REFERENCE		REFERENCE	
Average runs per trial day			0.005[a]		0.088[a]
1–2 runs per day	1,067 (25.5)	REFERENCE		REFERENCE	
3–4 runs per day	2,444 (58.4)	1.25 (1.07, 1.45)		1.23 (1.00, 1.52)	
5+ runs per day	677 (16.2)	1.02 (0.83, 1.25)		1.02 (0.77, 1.35)	
Average days per trial weekend			0.32		0.10[a]
Only 1 day	485 (11.6)	1.10 (0.89, 1.36)		1.16 (0.87, 1.54)	
1 or 2 days; it depends	1,680 (40.1)	1.03 (0.89, 1.18)		1.10 (0.91, 1.33)	
Usually 2 days, sometimes 3	1,701 (40.6)	REFERENCE		REFERENCE	
As many as possible (often 3)	320 (7.6)	0.84 (0.65, 1.08)		0.71 (0.49, 1.03)	
Grass surface			<0.001[a]		0.25
Never competed	767 (18.3)	REFERENCE		REFERENCE	

(Continued)

TABLE 1 | Continued

	N (%)	Any injury OR (95% CI)	Any injury *p*-value	Severe injury OR (95% CI)	Severe injury *p*-value
<6 times per year	1,882 (45.0)	1.32 (1.10, 1.58)		1.21 (0.93, 1.57)	
6+ times per year	1,536 (36.7)	1.50 (1.25, 1.81)		1.25 (0.96, 1.63)	
Dirt surface			0.46		0.90
Never competed	1,597 (38.2)	REFERENCE		REFERENCE	
<6 times per year	1,698 (40.6)	0.98 (0.84, 1.13)		1.02 (0.83, 1.24)	
6+ times per year	890 (21.3)	1.08 (0.91, 1.28)		0.96 (0.76, 1.22)	
Sand surface			0.042[a]		0.74
Never competed	2,645 (63.2)	REFERENCE		REFERENCE	
<6 times per year	1,253 (29.9)	1.19 (1.04, 1.37)		0.96 (0.80, 1.17)	
6+ times per year	287 (6.9)	1.09 (0.85, 1.40)		0.87 (0.60, 1.26)	
Turf surface			0.85		0.11[a]
Never competed	1,660 (39.7)	REFERENCE		REFERENCE	
<6 times per year	1,095 (26.2)	0.95 (0.81, 1.12)		1.26 (1.02, 1.57)	
6+ times per year	1,430 (34.2)	0.99 (0.85, 1.14)		1.13 (0.92, 1.39)	
Foam surface			0.43		0.70
Never competed	3,522 (84.2)	REFERENCE		REFERENCE	
<6 times per year	494 (11.8)	0.88 (0.72, 1.07)		0.89 (0.68, 1.17)	
6+ times per year	169 (4.0)	0.96 (0.69, 1.33)		0.95 (0.61, 1.47)	
Rubber surface			0.001[a]		0.020[a]
Never competed	2,761 (66.0)	REFERENCE		REFERENCE	
<6 times per year	1,054 (25.2)	0.95 (0.82, 1.10)		1.03 (0.84, 1.25)	
6+ times per year	370 (8.8)	0.64 (0.51, 0.81)		0.62 (0.44, 0.88)	
Other surface			0.15[a]		0.41
Never competed	3,972 (94.9)	REFERENCE		REFERENCE	
<6 times per year	141 (3.4)	1.36 (0.97, 1.92)		0.78 (0.47, 1.31)	
6+ times per year	72 (1.7)	1.25 (0.77, 2.01)		0.67 (0.31, 1.48)	
Times competed at National level			<0.001[a]		0.22
0 (never)	2,539 (61.0)	REFERENCE		REFERENCE	
1	532 (12.8)	1.21 (1.00, 1.47)		1.23 (0.94, 1.59)	
2	352 (8.5)	1.66 (1.32, 2.09)		1.28 (0.95, 1.72)	
3	195 (4.7)	1.40 (1.04, 1.89)		1.03 (0.69, 1.54)	
4	124 (3.0)	2.15 (1.47, 3.14)		1.66 (1.07, 2.57)	
5	76 (1.8)	1.18 (0.74, 1.88)		1.21 (0.68, 2.15)	
>5	345 (8.3)	1.51 (1.19, 1.91)		1.07 (0.79, 1.46)	
Times competed at International level			0.004[a]		0.95
0 (never)	3,909 (93.4)	REFERENCE		REFERENCE	
1	83 (2.0)	1.85 (1.19, 2.89)		0.94 (0.49, 1.80)	
>1	192 (4.6)	1.36 (1.01, 1.83)		0.95 (0.63, 1.43)	

[a] *$p < 0.20$ and retained for model building.*

at competition standards, but guide wires are attached so that the dog is funneled between the poles so that the dog must continue straight; (4) Other.

Our outcome of interest was injury history, defined as an injury that kept the dog from participating in agility for over a week. A secondary outcome of "severe" injury was defined as at least one injury that kept the dog from participating in agility for <3 months (4 months or longer), or lead to retirement from agility.

All models were adjusted for dog age to account for greater lifetime injury risk among older dogs. Associations between each competition and training variables with injury history were first assessed in dog age adjusted logistic regression models. Final adjusted models were constructed separately for competition and training variables to explore adjusted associations. All models were built using backward selection, starting with candidate variables associated with the outcome at $p < 0.20$ in dog age only adjusted models and ending with all variables associated

TABLE 2 | Coefficients from adjusted model with competition level factors only for any injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.15 (1.12, 1.17)	<0.001
Jump height difference		0.003
Jumping > 4" above height	1.50 (1.04, 2.16)	
Jumping 2–4" above height	1.31 (1.00, 1.71)	
Jumping 0–2" above height	1.01 (0.83, 1.21)	
Jumping 0–2" below height	REFERENCE	
Jumping 2–4" below height	0.78 (0.64, 0.95)	
Jumping 4–6" below height	0.98 (0.78, 1.24)	
Jumping >6" below height	1.10 (0.85, 1.43)	
Approach to competition planning		0.002
Plan around availability/schedule	REFERENCE	
Plan around a big event	1.30 (0.85, 1.99)	
Mix of the two	1.34 (1.15, 1.57)	
Other approach	0.91 (0.64, 1.27)	
Average runs per trial day		0.031
1–2 runs per day	REFERENCE	
3–4 runs per day	1.15 (0.98, 1.34)	
5+ runs per day	0.92 (0.74, 1.14)	
Rubber surface		0.005
Never competed	REFERENCE	
<6 times per year	1.01 (0.87, 1.18)	
6+ times per year	0.68 (0.53, 0.86)	
Times competed at National level		0.003
0 (never)	REFERENCE	
1	1.17 (0.96, 1.44)	
2	1.54 (1.21, 1.96)	
3	1.27 (0.93, 1.73)	
4	1.80 (1.21, 2.66)	
5	1.09 (0.68, 1.77)	
>5	1.24 (0.96, 1.60)	

with the outcome at $p < 0.05$. Using backward selection, the variable with the largest *p*-value was removed at each step until all remaining variables were associated with the outcome at $p < 0.05$. We used an available case approach to missing data, after restricting to those who completed >90% of the survey and answered our primary outcome question. This process was repeated for the outcome of severe injury. All analyses were conducted using Stata.

RESULTS

Our sample included 4,197 responses that had >90% survey completion and provided an answer to the primary injury history question. Of the 4,197 dogs, 1,737 (41.4%) reported an injury history and 629 (15.0%) reported a history of severe injury.

Nearly all competition level factors were associated with injury history in age-adjusted models (**Table 1**). After backward selection, the difference between jump height and dog height, average runs per trial day, times competing at the national level, planning around big events, and competing on rubber matting were associated with injury risk at $p < 0.05$ (**Table 2**). In this model, dogs jumping 4 or more inches above their height had the highest risk of injury (OR: 1.50 compared to dogs jumping 0–2" below their height), and dogs jumping 2–4" above their height were also at increased risk (OR: 1.31). The lowest risk was observed for dogs jumping 2–4" below their height. Dogs completing 3–4 runs per trial day had a greater risk of injury history (OR: 1.15) than dogs with only 1–2 runs per day, but dogs completing 5 or more runs per trial day had a lower risk than both groups (OR: 0.92 compared to the 1–2 runs per day group).

TABLE 3 | Coefficients from adjusted model with competition level factors only for severe injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.19 (1.16, 1.23)	<0.001
Approach to competition planning		0.004
Plan around availability/schedule	REFERENCE	
Plan around a big event	1.31 (1.08, 1.60)	
Mix of the two	1.90 (1.15, 3.12)	
Other approach	1.35 (0.89, 2.03)	
Rubber surface		0.033
Never competed	REFERENCE	
<6 times per year	1.04 (0.85, 1.27)	
6+ times per year	0.65 (0.46, 0.92)	

Dogs who had competed at a national competition had greater odds of injury history across all number of times competing relative to those who had never competed. The dogs of handlers who reported planning around a big event (OR: 1.30) or a mix of planning around a big event and options available (OR: 1.34) had higher odds of dogs with injury history compared to handlers who reported primarily planning around trial options available. Interestingly, dogs who competed 6 or more times per year on rubber matting had a lower odds of injury history compared to dogs with no history of competing on the surface (OR: 0.68) while dogs who competed 5 or fewer times had a similar risk of injury history (OR: 1.01).

Associations with severe injury were generally smaller in magnitude for competition-level variables, and fewer variables were carried forward to adjusted model building (**Table 1**). Notably, the age-adjusted association between trial weekends per year and severe injury was different from that with any injury. Trialing < 26+ weekends per year was associated with greater risk of severe injury, whereas the lowest risk of any injury was observed for dogs trialing the fewest weekends per year. The age-adjusted association with competing at the international level was also different for any injury (where greater risk was observed for dogs with a history of competing at the international level) and severe injury (where very little difference in risk was observed). The final adjusted model (**Table 3**) included only planning around big events and competing on a rubber surface, where similar associations to any injury were observed.

TABLE 4 | Age adjusted associations between training risk factors and injury history.

	N (%)	**Any injury OR (95% CI)**	**Any injury *p*-value**	**Severe injury OR (95% CI)**	**Severe injury *p*-value**
First started any agility-specific training			<0.001[a]		0.003[a]
<16 weeks	625 (14.9)	1.29 (1.00, 1.65)		1.00 (0.71, 1.42)	
4–6 months	876 (20.9)	1.77 (1.40, 2.23)		1.30 (0.95, 1.78)	
6–12 months	1,211 (28.9)	1.86 (1.49, 2.31)		1.63 (1.22, 2.17)	
13–18 months	657 (15.7)	1.50 (1.18, 1.91)		1.18 (0.85, 1.64)	
19–24 months	295 (7.0)	1.44 (1.07, 1.94)		1.17 (0.78, 1.75)	
2+ years	533 (12.7)	REFERENCE		REFERENCE	
Age competed in first fun match			<0.001[a]		0.020[a]
<12 months	86 (2.1)	1.04 (0.63, 1.71)		0.56 (0.23, 1.35)	
12–15 months	566 (13.6)	1.22 (0.94, 1.59)		1.12 (0.78, 1.60)	
16–18 months	951 (22.8)	1.45 (1.15, 1.84)		1.50 (1.10, 2.05)	
19–24 months	899 (21.6)	1.52 (1.20, 1.93)		1.25 (0.91, 1.72)	
25–30 months	320 (7.7)	1.44 (1.07, 1.93)		1.05 (0.70, 1.57)	
31–36 months	106 (2.5)	0.82 (0.52, 1.29)		0.85 (0.45, 1.61)	
3+ years	455 (10.9)	REFERENCE		REFERENCE	
N/A – no fun match	787 (18.9)	1.10 (0.86, 1.40)		1.00 (0.72, 1.39)	
Age competed in first trial			<0.001[a]		0.36
<16 months	203 (4.9)	0.98 (0.70, 1.38)		1.08 (0.68, 1.73)	
16–18 months	837 (20.0)	1.27 (1.03, 1.57)		1.18 (0.89, 1.56)	
19–24 months	1,566 (37.5)	1.45 (1.21, 1.75)		1.20 (0.93, 1.54)	
25–30 months	640 (15.3)	1.49 (1.19, 1.86)		1.28 (0.95, 1.73)	
31–36 months	200 (4.8)	0.99 (0.71, 1.39)		0.82 (0.50, 1.33)	
3+ years old	732 (17.5)	REFERENCE		REFERENCE	
Age any jumps			<0.001[a]		<0.001[a]
>18 months	701 (16.9)	REFERENCE		REFERENCE	
<3 months	101 (2.4)	0.66 (0.40, 1.08)		0.31 (0.11, 0.86)	
3–6 months	500 (12.1)	1.53 (1.20, 1.95)		1.02 (0.72, 1.46)	
7–9 months	852 (20.6)	1.70 (1.38, 2.11)		1.63 (1.22, 2.17)	
10–12 months	1,015 (24.5)	1.73 (1.41, 2.13)		1.49 (1.13, 1.96)	
13–15 months	744 (18.0)	1.38 (1.11, 1.72)		1.38 (1.03, 1.86)	
16–18 months	233 (5.6)	1.52 (1.11, 2.07)		1.16 (0.75, 1.79)	
Age elbow height jumps			<0.001[a]		0.009[a]
>18 months	885 (21.7)	REFERENCE		REFERENCE	
<7 months	72 (1.8)	1.06 (0.63, 1.78)		0.52 (0.20, 1.33)	
7–9 months	281 (6.9)	1.17 (0.88, 1.56)		0.95 (0.63, 1.43)	
10–12 months	897 (22.0)	1.36 (1.12, 1.66)		1.12 (0.86, 1.47)	
13–15 months	1,385 (34.0)	1.60 (1.34, 1.92)		1.43 (1.12, 1.81)	
16–18 months	553 (13.6)	1.31 (1.05, 1.64)		1.02 (0.75, 1.40)	
Age full height jumps			0.009[a]		0.35
>18 months	1,461 (35.6)	REFERENCE		REFERENCE	
<10 months	54 (1.3)	0.75 (0.41, 1.36)		0.80 (0.33, 1.93)	
10–12 months	349 (8.5)	1.00 (0.79, 1.28)		0.99 (0.70, 1.38)	
13–15 months	1,139 (27.7)	1.23 (1.05, 1.45)		1.13 (0.90, 1.41)	
16–18 months	1,104 (26.9)	1.27 (1.08, 1.50)		1.24 (0.99, 1.55)	
Age backside at any height			0.017[a]		0.75
>18 months	1,907 (50.5)	REFERENCE		REFERENCE	
<10 months	96 (2.5)	1.22 (0.80, 1.87)		0.96 (0.51, 1.79)	
10–12 months	354 (9.4)	1.18 (0.93, 1.51)		1.08 (0.76, 1.53)	
13–15 months	701 (18.6)	1.31 (1.09, 1.58)		1.09 (0.84, 1.42)	

(Continued)

TABLE 4 | Continued

	N (%)	Any injury OR (95% CI)	Any injury *p*-value	Severe injury OR (95% CI)	Severe injury *p*-value
16–18 months	718 (19.0)	1.28 (1.07, 1.53)		1.18 (0.92, 1.52)	
Age backside at full height			0.013[a]		0.67
>18 months	2,246 (58.9)	REFERENCE		REFERENCE	
<13 months	176 (4.6)	0.90 (0.64, 1.25)		0.74 (0.44, 1.23)	
13–15 months	579 (15.2)	1.30 (1.07, 1.58)		1.03 (0.78, 1.36)	
16–18 months	810 (21.3)	1.20 (1.01, 1.42)		1.02 (0.80, 1.29)	
Tunnel age			<0.001[a]		<0.001[a]
>18 months	641 (15.5)	REFERENCE		REFERENCE	
<3 months	600 (14.5)	1.14 (0.90, 1.46)		0.74 (0.51, 1.08)	
3–6 months	1,080 (26.2)	1.60 (1.30, 1.97)		1.45 (1.09, 1.92)	
7–9 months	713 (17.3)	1.70 (1.36, 2.14)		1.67 (1.23, 2.26)	
10–12 months	513 (12.4)	1.56 (1.23, 1.99)		1.56 (1.12, 2.15)	
13–15 months	396 (9.6)	1.51 (1.16, 1.96)		1.44 (1.02, 2.04)	
16–18 months	184 (4.5)	1.43 (1.01, 2.01)		1.13 (0.69, 1.85)	
Curved tunnel age			<0.001[a]		0.001[a]
>18 months	705 (17.0)	REFERENCE		REFERENCE	
<3 months	208 (5.0)	1.10 (0.79, 1.54)		0.57 (0.32, 1.01)	
3–6 months	857 (20.6)	1.40 (1.14, 1.73)		1.11 (0.82, 1.49)	
7–9 months	935 (22.5)	1.48 (1.20, 1.82)		1.48 (1.12, 1.95)	
10–12 months	684 (16.5)	1.59 (1.27, 1.99)		1.48 (1.10, 2.00)	
13–15 months	506 (12.2)	1.54 (1.22, 1.96)		1.50 (1.09, 2.05)	
16–18 months	259 (6.2)	1.22 (0.91, 1.65)		0.96 (0.62, 1.48)	
Aframe age			0.003[a]		0.18[a]
>18 months	1,159 (28.1)	REFERENCE		REFERENCE	
<10 months	317 (7.7)	1.13 (0.87, 1.46)		0.85 (0.58, 1.24)	
10–12 months	821 (19.9)	1.02 (0.84, 1.23)		1.05 (0.81, 1.35)	
13–15 months	1,203 (29.2)	1.35 (1.14, 1.60)		1.16 (0.92, 1.46)	
16–18 months	626 (15.2)	1.27 (1.03, 1.55)		1.30 (0.99, 1.70)	
Dogwalk age			0.002[a]		0.31
>18 months	1,150 (27.9)	REFERENCE		REFERENCE	
<10 months	423 (10.3)	0.90 (0.71, 1.14)		0.83 (0.59, 1.16)	
10–12 months	934 (22.6)	1.16 (0.97, 1.39)		1.00 (0.78, 1.28)	
13–15 months	1,083 (26.2)	1.35 (1.14, 1.61)		1.17 (0.93, 1.48)	
16–18 months	537 (13.0)	1.12 (0.90, 1.39)		1.07 (0.80, 1.44)	
Teeter age			0.002[a]		0.50
>18 months	1,134 (28.9)	REFERENCE		REFERENCE	
<10 months	389 (9.9)	0.80 (0.63, 1.02)		0.83 (0.58, 1.17)	
10–12 months	847 (21.6)	1.11 (0.92, 1.33)		1.02 (0.79, 1.31)	
13–15 months	1,010 (25.8)	1.26 (1.06, 1.50)		1.13 (0.89, 1.43)	
16–18 months	543 (13.8)	1.23 (0.99, 1.52)		1.08 (0.81, 1.44)	
Any weaves age			0.005[a]		0.129[a]
>18 months	1,037 (24.8)	REFERENCE		REFERENCE	
<7 months	205 (4.9)	1.10 (0.80, 1.50)		0.81 (0.50, 1.31)	
7–9 months	462 (11.1)	1.06 (0.84, 1.33)		1.02 (0.74, 1.41)	
10–12 months	825 (19.7)	1.04 (0.86, 1.26)		0.99 (0.76, 1.30)	
13–15 months	1,148 (27.5)	1.37 (1.15, 1.64)		1.21 (0.95, 1.54)	
16–18 months	503 (12.0)	1.25 (1.00, 1.56)		1.35 (1.01, 1.81)	

(Continued)

TABLE 4 | Continued

	N (%)	Any injury OR (95% CI)	Any injury *p*-value	Severe injury OR (95% CI)	Severe injury *p*-value
Sequences closed weaves			0.002[a]		0.001[a]
>18 months	1,464 (35.0)	REFERENCE		REFERENCE	
<10 months	135 (3.2)	0.74 (0.50, 1.08)		0.47 (0.23, 0.94)	
10–12 months	495 (11.8)	1.00 (0.81, 1.24)		1.12 (0.83, 1.49)	
13–15 months	1,250 (29.9)	1.22 (1.04, 1.42)		1.10 (0.88, 1.38)	
16–18 months	838 (20.0)	1.31 (1.10, 1.56)		1.50 (1.18, 1.89)	
Aframe contact			0.77		0.60
2 on 2 off	1,900 (47.7)	REFERENCE		REFERENCE	
4 on	133 (3.3)	0.86 (0.59, 1.25)		0.86 (0.59, 1.25)	
Other/no specific behavior	164 (4.1)	1.09 (0.78, 1.51)		1.09 (0.78, 1.51)	
Running	1,785 (44.8)	0.97 (0.85, 1.11)		0.97 (0.85, 1.11)	
Dogwalk contact			0.023[a]		0.12[a]
2 on 2 off	2,528 (60.3)	REFERENCE		REFERENCE	
4 on	199 (4.8)	0.78 (0.58, 1.06)		0.74 (0.48, 1.15)	
Other/no specific behavior	146 (3.5)	0.99 (0.71, 1.40)		0.90 (0.56, 1.43)	
Running	1,317 (31.4)	0.82 (0.71, 0.94)		0.80 (0.66, 0.98)	
Teeter contact			<0.001[a]		0.028[a]
2 on 2 off	2,203 (52.7)	REFERENCE		REFERENCE	
4 on (down)	311 (7.4)	0.73 (0.56, 0.93)		0.76 (0.52, 1.09)	
4 on (standing)	1,200 (28.7)	0.78 (0.67, 0.90)		0.87 (0.72, 1.07)	
No specific behavior	240 (5.7)	0.69 (0.52, 0.92)		0.65 (0.43, 0.98)	
Other	224 (5.4)	0.74 (0.55, 0.99)		0.58 (0.37, 0.91)	
Weave training method			0.14[a]		<0.001[a]
2 × 2	1,912 (45.8)	REFERENCE		REFERENCE	
Channel	1,329 (31.8)	0.86 (0.74, 0.99)		0.67 (0.54, 0.82)	
Guide wires	462 (11.1)	0.99 (0.80, 1.22)		0.68 (0.51, 0.92)	
Other	474 (11.4)	0.86 (0.70, 1.06)		0.66 (0.49, 0.89)	

[a]*$p < 0.20$ and retained for model building.*

Most training level variables were also associated with injury history in age-adjusted models (**Table 4**). However, in model building, only three variables remained significant at $p < 0.05$: age starting any jump training, age starting any teeter training, and age starting any weave training (**Table 5**). In this model, the association between injury risk and jump training was mostly in the expected direction, with younger age of starting associated with higher odds of injury except that dogs started very young (<3 months old) appeared not to be at increased risk. In adjusted models, dogs that started weave and teeter training at earlier ages (among dogs who started jump training at the same age) had lower risk of injury. Thus, the highest risk in this model belonged to dogs who started jump training early (between 3 and 12 months), but did not start training weaves or teeter before 18 months.

Associations with severe injury were generally similar for training level factors (**Table 4**). Notably, the weave training method showed greater association with severe injury (more severe injury among those trained with 2 × 2 method than all others). In the final adjusted model for severe injury three variables were significant at $p < 0.05$: age starting curved tunnels, age sequencing with closed weave poles, and weave training method (**Table 6**). In this adjusted model, all methods for weave training showed lower odds of severe injury compared to the 2 × 2 method, and the lowest risk of severe injury was observed among dogs who started curved tunnels and sequencing closed weaves at the youngest ages. A general increase in risk was observed for starting curved tunnels between 3 and 15 months, holding the weave factors constant.

DISCUSSION

As was hypothesized, starting jump training at an earlier age was associated with greater risk of injury relative to starting after 18 months. The lower risk of injury associated with dogs starting jump training at over 18 months of age could be due to the fact that the majority of dogs are skeletally mature at 18 months. It is possible that the high impact of jump training before skeletal maturity may increase the risk of injuries or musculoskeletal conditions. High impact repetitive sport activities in children have been shown to contribute to

TABLE 5 | Coefficients from adjusted model with training level factors for any injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.17 (1.14, 1.20)	<0.001
Age any jumps		<0.001
>18 months	REFERENCE	
<3 months	0.98 (0.54, 1.75)	
3–6 months	2.39 (1.66, 3.43)	
7–9 months	2.47 (1.77, 3.44)	
10–12 months	2.24 (1.63, 3.07)	
13–15 months	1.58 (1.16, 2.15)	
16–18 months	1.55 (1.09, 2.20)	
Teeter age		0.018
>18 months	REFERENCE	
<10 months	0.59 (0.43, 0.83)	
10–12 months	0.82 (0.62, 1.08)	
13–15 months	0.92 (0.71, 1.19)	
16–18 months	0.94 (0.73, 1.23)	
Any weaves age		0.034
>18 months	REFERENCE	
<7 months	0.89 (0.58, 1.37)	
7–9 months	0.75 (0.53, 1.07)	
10–12 months	0.67 (0.49, 0.92)	
13–15 months	0.92 (0.69, 1.24)	
16–18 months	0.89 (0.66, 1.20)	

TABLE 6 | Coefficients from adjusted model with training level factors for severe injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.20 (1.17, 1.24)	<0.001
Curved tunnel age		0.001
>18 months	REFERENCE	
<3 months	0.74 (0.48, 1.14)	
3–6 months	1.39 (0.97, 1.98)	
7–9 months	1.55 (1.08, 2.24)	
10–12 months	1.40 (0.96, 2.04)	
13–15 months	1.31 (0.90, 1.91)	
16–18 months	1.05 (0.64, 1.75)	
Sequences closed weaves		0.037
>18 months	REFERENCE	
<10 months	0.50 (0.24, 1.04)	
10–12 months	1.08 (0.76, 1.53)	
13–15 months	0.97 (0.73, 1.28)	
16–18 months	1.29 (0.97, 1.70)	
Weave training method		0.002
2 × 2	REFERENCE	
Channel	0.69 (0.56, 0.85)	
Guide wires	0.73 (0.54, 0.99)	
Other	0.72 (0.53, 0.97)	

primary periphyseal stress injuries (13, 14). Previous canine biomechanical studies evaluating the effects of jumping on forelimb muscular activation have shown that the jump task is the most physiologically demanding task for all evaluated forelimb muscles (15). A study by Söhnel et al. evaluated limb length and stiffness during jumping in agility dogs with greater than and less than 4 years of agility experience (16). They found that, during landing, beginner dogs (those with <4 years of agility experience) had 17% higher limb compression during stance phase (16). No studies have evaluated how this higher limb compression and higher muscular activation may impact development of bones and joints in skeletally immature dogs.

It is common practice to start younger dogs jumping lower jump heights, and to increase the jump height as the dog ages and approaches skeletal maturity, often determined by radiographic closure of the growth plates. Jumping a lower jump height is thought to exert less force on the developing bones and joints, and therefore be less likely to cause developmental musculoskeletal conditions or injury. While biomechanical studies have shown that increasing jump height increases peak vertical force upon landing with the forelimbs, and increases angulation of the scapulohumeral and sacroiliac joints, no studies have correlated the kinematic and kinetic findings with injury development or risk (17, 18). Based on the findings of this survey, it does not appear that starting jumping at a lower jump height when younger is protective of injury. However, competition jump height in relation to dog height was correlated with injury risk. Jumping 2–4" and jumping >4" above the height of the withers was associated with an increased risk of injury. This finding may be due to the increased neck angulation, lumbar spine extension and shoulder flexion as jump height increases, as well as the increased peak vertical force with higher jump heights and steeper landing angles (18, 19). Further studies are needed to prospectively evaluate effect of jump training on musculoskeletal development and injury incidence, as well as the association of altered kinetics and kinematics of increasing jump height and injury development.

Many variables thought to be associated with injury risk in agility dogs were not significant in adjusted models. Counter to our hypothesis, contact method (stopped vs. running) was not predictive in adjusted models. We hypothesized that stopped contacts would be correlated with a higher injury risk due to the increased deceleration (braking) forces experienced during downhill locomotion (20). Multiple studies have evaluated the kinetics and kinematics of the A-frame obstacle (15, 21–23). These studies have shown that ascent up a full height A-frame requires greater propulsive forces than a lower height A-frame (22), that range of motion in the lumbar spine changes during the different phases of obstacle completion, with lumbar flexion noted during the section of incline to apex and lumbar extension noted during the approach to incline and again from the apex to decline sections (23). As injury is likely multi-factorial, there are conflicting variables that make it hard to elucidate the exact effects of particular variables on injury risk.

Training running contacts instead of stopped contacts, especially a running dogwalk, has become more popular in recent years as a way to increase course speed and competitiveness. Other data from this survey indicates that there may be a link between competitiveness (higher levels of competition, participation in national/international events) and injury risk. Therefore, it is possible that running contacts, in and of themselves, are associated with reduced mechanical loads and decreased injury risk, but this benefit is counteracted by their more common use among faster, highly competitive dogs.

Anecdotally it is thought that performing the weave obstacle places substantial stress on the shoulders and spine and that, as a result, training weaves before skeletal maturity is not recommended. In the adjusted model, there was a decreased risk of injury when weave training was started prior to 7 months of age (and all ages prior to 18 months), leading us to reject this hypothesis. It is unknown whether this represents a true decrease in injury risk since some combinations of starting ages were observed only in a small number of dogs (e.g., most dogs started jump training prior to weaves). If starting weave training early does reduce injury risk it is possible that weave training improves overall body awareness and coordination, which has been shown to decrease injury risk in human athletes (24–26). Agility, balance and coordination training is recommended in pre-pubescent human athletes in order to take advantage of increased synaptoplasticity and prevent injuries (27). Weave training method, while not retained in the model for general injury risk, was retained in the model for severe injury risk. Dogs who did the 2 × 2 weave training method had an increased risk of severe injury compared to the channel method or guide-wire method of training. It is possible that the 2 × 2 method requires more repetitions during training, thereby resulting in overuse or overtraining injuries. Biomechanical studies are needed to evaluate kinetics and kinematics of weave obstacle execution and different training methods, and how that may relate to injury risk and prevention.

Surprisingly, early age at completing a final teeter behavior was also associated with decreased risk of injury in the adjusted model. This observation could be due to more experienced or more effective trainers/handlers teaching these dogs, thereby being able to complete this particular training earlier. Teeter training also involves more balance and coordination than other contact behaviors. It is possible that the dogs that are able to learn this behavior quickly and early have more coordination and body awareness than dogs that take longer to learn this skill, thereby possibly decreasing the risk of injury. In human studies, improved balance is correlated with decreased injury risk and enhanced athletic performance (28). While there are no studies evaluating the effect of balance on canine injury risk or athletic performance, there are likely to be similarities to the effects found in the human literature.

In the Cullen et al. study, 26.8% of injuries reported had an undefined or non-specific cause of injury, i.e., the injury was not caused by contact with a certain obstacle or in relation to surface type (29). This subset of injuries may be due to chronic overuse or overtraining. We had hypothesized that increasing number of competition days per year and runs per competition day would be associated with increased injury risk. Increased competition load, defined as the cumulative amount of stress placed on an individual from single or multiple competitions over a period of time (30), has been associated with increased injury risk in the human literature (31). Based on the data from this survey there was no association between frequency of competition days per year and injury risk. There was, however, an association between number of runs per competition day and injury risk. Runs per day was associated with injury, with 3-4 runs per day having an increased risk compared to 1–2 runs per day. Injury risk is increased if the intensity, frequency or duration of loading is beyond the tissue's capacity or if the recovery between loading is insufficient (30). It is possible that 3–4 runs a day increases injury risk due to decreased recovery or tissue overload, compared to 1–2 runs a day. It has also been suggested that fatigue due to repetitive loading may increase the susceptibility to injury (30), which could also play a role in the increased injury rates in the 3–4 runs per day (32). The reported decreased injury risk in dogs who complete 5+ runs per day is likely reverse causality, as dogs who have sustained an injury are less likely to be capable of 5+ runs a day or the handlers are more cautious about the number of runs. These data indicate a need for more studies evaluating competition load in our canine athletes and how that load affects injury development.

Periodization is the process of planning training programs to include variations in training loads and cycles in order to maximize physiological adaptations for competition performance (33). The human literature evaluating periodization techniques is extensive and complex. There are many periodization methods and the training and competition needs vary by sport. Human studies have shown that detailed training scheduling and periodization results in improved strength and decreased risk of sports related injuries, but this has not been evaluated in canine athletes (24–26, 30, 33–38). There is also evidence in the human literature that training periodization lowers the risk of overtraining and increases the chance of peaking at key competitions (33). Periodization is not currently a consideration for the majority of canine athletes and there are no studies evaluating the effect periodization has on canine, or even equine, athletic performance.

In evaluating periodization in this study, contrary to expectation, we found that canine athletes whose owners planned training and competition schedules actually had a higher risk of injury. This is likely due to multiple factors. This survey was retrospective in nature, and exact training and planning methods could not be assessed. It is also possible that owners were not performing true periodization with cycles of very specific increases and decreases in training load, but instead more calendar schedule planning of training days and competition days. The limitations of the retrospective survey combined with the complexity of periodization techniques makes it challenging to assess relationship to injury. However, the relationship between injury risk and training planning could be correlated with the hypothesis that faster, more competitive dogs are more likely to get injured, as the owners of these dogs are more likely to be planning their competitions and training based on large national and international events.

Prospective studies are also needed to evaluate the effect of true training periodization on canine athletic performance and injury risk.

Injury risk in relation to competition and training surfaces has been extensively evaluated in equine and human medicine (3, 39, 40). Relationships between surface type and risk of injury have been minimally evaluated in canine sports, with one study suggesting a correlation between track surface and injury in racing greyhounds (41). We had originally hypothesized that competing on a turf surface would have the lowest risk of injury. Surprisingly, and counter to our hypothesis, dogs that competed on rubber matting had a lower risk of injury. Rubber matting has fallen out of favor in many agility venues due to the thought that there is an increased risk of slipping on that particular surface. It is possible that handlers with faster dogs specifically choose to not compete in venues with rubber matting due to concern for injury, which would also support the correlation of speed with injury risk. There may be other factors involved with the dogs that are competing more frequently on rubber that potentially decreases their injury risk, confounding the correlation between rubber matting and injury risk. More studies are needed to prospectively evaluate speed and correlation with injury in agility dogs, as well as evaluate the effect that surface has on biomechanics, performance and injury risk.

Limitations of this study include those associated with a cross-sectional, retrospective survey. These include potential self-selection bias which may result in the survey sample not being representative of the total agility dog population. Participant recall and handler-reported data may have also resulted in potential inaccuracies. Also, since this survey was in English but distributed world-wide, it is possible that there were inaccuracies due to variations in terminology and training methods between countries and geographical regions. Future studies should consider collaborating with agility organizations to obtain data from all competitors in order to address potential sampling error and self-selection bias.

These data provide valuable current insight into the possible effects that training and competition variables may have on injury risk in agility dogs. While no definitive recommendations can be made regarding training or competition based on these data, they provide a starting point for future, prospective studies. Specifically, this survey indicates a need for further studies evaluating the biomechanics of agility obstacles and obstacle training techniques and their effect on musculoskeletal development and injuries. There is also a significant need for studies evaluating strength and conditioning programs and training periodization in canine athletics, both for performance and injury prevention. With the increasing popularity of companion dog sports, there is a definitive need for research on sport specific training and injury prevention in order to provide better training and care recommendations to these canine athletes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the Ohio State University Office of Responsible Research Practices determined the project was exempt from IRB review because it was an owner-based internet survey and the information was recorded without direct or indirect identifiers. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

APM, AS, and NK contributed to the study idea, survey, and study design. AS collected data, performed data entry, and statistical analysis. All authors contributed to the manuscript preparation and revisions for submission.

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REVIEW
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Canine Geriatric Rehabilitation: Considerations and Strategies for Assessment, Functional Scoring, and Follow Up

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Geriatric animals account for half of the pet population in the United States with their numbers increasing annually. Furthermore, a significant percentage of veterinary patients with movement limitations could be grossly categorized as geriatric and living within the end stage of their predicted lifespans. Because mobility is correlated to quality of life and time to death in aging dogs, a major goal in optimizing canine geriatric health is to improve functional movement. Within the geriatric population, identifying disabilities that affect daily living and quality of life may be used by the rehabilitation practitioner to provide stronger prognoses, treatment goals, and outcome measures. Examples of such means are described within this review. In human medicine, the concept of "optimal aging", or "healthy aging", has emerged in which inevitable detrimental age-related changes can be minimized or avoided at various levels of physical, mental, emotional, and social health. Both environment and genetics may influence aging. Identifying and improving environmental variables we can control remain a key component in optimizing aging. Furthermore, diagnosing and treating age related comorbidities common to older populations allows for improved quality of life and is often directly or indirectly affecting mobility. Obesity, sarcopenia, and a sedentary lifestyle are a trifecta of age-related morbidity common to both people and dogs. Healthy lifestyle choices including good nutrition and targeted exercise play key roles in reducing this morbidity and improving aging. Disablement models act as essential tools for creating more effective physiotherapy plans in an effort to counter dysfunction and disability. Within these models, functional testing represents a standard and validated means of scoring human geriatric function as well as monitoring response to therapy. Because of the great need in dogs, this review aims to provide a reasonable and testable standardized framework for canine functional scoring. We believe a complete assessment of canine geriatric patients should comprise of identifying environmental variables contributing to health status; diagnosing comorbidities related to disease and aging; and characterizing disability with standardized methods. Only through this process can we construct a comprehensive, reasonable, and targeted rehabilitation plan with appropriate follow up aimed at healthy aging.

Keywords: canine (dog), geriatric assessment, function, healthy aging, functional assessment and evaluation, morbidity, rehabilitation, physical therapy

INTRODUCTION

The typical geriatric patient presents to a veterinary rehabilitation service in one of three ways: noted decline in mobility at home; post-surgery physiotherapy; or a decline in mobility noted by another veterinarian. Often times the change in functional movement remains vague until examination and, more often than not, can be attributed to multiple underlying disease processes. Such examples might include an 8-year-old German Shepherd with hip dysplasia, elbow dysplasia, sarcopenia, and degenerative lumbosacral stenosis; or a 10-year-old Labrador Retriever suffering from hypothyroidism, bilateral cranial cruciate disease, copper hepatopathy, and obesity. Although the importance of identifying the major complaint cannot be understated or lost in the complexity of the case, such patients require comprehensive evaluation and therapy for the best outcomes.

As rehabilitation specialists, we attempt to optimize functional movement in our patients. Such an approach is holistic and inevitably is composed of nutritional therapy, pain management, rehabilitative exercises, treatment of co-morbidities, and surgical intervention when indicated. A significant percentage of patients with movement limitations could be grossly categorized as geriatric and living within the end stage of their predicted lifespans (1–3). Within the United States, a more recent census predicted that the geriatric population may amount to nearly 50% of the 78 million owned dogs (1). Given the number of geriatric pets, the relatability of their diseases, and their shared human environment; exploring the role of rehabilitative therapies to optimize geriatric function, quality of life, and longevity warrant discussion and exploration.

The goals of this canine geriatric rehabilitation review are to:

1. Summarize the current pertinent literature and practice
2. Establish a logical, fluid, and comprehensive method for patient assessment, goal setting, and follow up
3. Propose a reasonable and testable framework for standardized functional scoring of the geriatric patient.

DEFINING HEALTHY AGING, VIGOR, AND TASK DEPENDENT MOVEMENT

Healthy Aging

Although there remains a paucity of literature, the natural processes of aging have been studied in dogs and could be considered to be a potential model for human aging (2–6). An individual's life span is influenced by both genetic and environmental factors; however, the length of time one lives often fails to correlate with the quality of life throughout that time. In human medicine, the concept of "optimal aging", or "healthy aging", has emerged in which inevitable detrimental age-related changes can be minimized or avoided at various levels of physical, mental, emotional, and social health (7, 8). Healthy aging may be reflected as a delay in the onset of chronic or age-related disease, a reduction in morbidity associated with such disease, an increase in longevity, or any such combination. Although the concept of healthy aging is relatable and understandable, defining the contributing factors and methods to classify a patient (vigor scoring or functional task dependent movement) presents a challenge.

Variables affecting healthy aging in people can be translated to dogs and may include but are not limited to: medical care, social/family support, healthy lifestyle, and environmental conditions (8). These variables may change any time during the lifespan of an animal. Implementing better choices at a younger age may have an even greater impact. As veterinary rehabilitation specialists, we tend to have less influence over establishing better choices in younger healthy dog populations and often encounter our patients for the first time as geriatrics. Regardless of patient age, we often have more success optimizing our patient care if we work with families to identify which variables are impairing the patient and how we can improve them (**Table 1**).

Adams et al. (2) distinguished *diseases of aging* from the *process of aging*. Various diseases are more likely to occur as an animal ages, especially chronic diseases, and often limit longevity and quality of life. However, all animals experience a *process of aging* in which biochemical and cellular changes lead to progressive senescence of cells and organs and a reduction in functional reserve. Geriatric dogs with mobility issues also commonly present with chronic age-related primary or secondary diseases (for example: diabetes, hypothyroidism, cancer, autoimmune issues, complicated urinary tract infections, etc.). Although it may be too late to prevent such morbidities, many of these diseases are treatable so as to minimize their adverse effects (compression of morbidity) and thereby improve the process of healthy aging (9). Compression of morbidity is not a foreign concept and is regularly employed by veterinarians. As clinicians, we prefer treatments that are curative or near curative, but often must focus on improving circumstances within a pet's remaining lifespan (such as palliative care for appendicular osteosarcoma) or attempting to reduce the rate of a pet's disease progression (such as rehabilitative and nursing care for degenerative myelopathy).

Vigor

The concept of "vigor" is an assessment of physical abilities (strength, endurance, balance, spatial awareness, and flexibility), motivation/attitude, comfort, and comorbidities to help further classify daily function and help maximize healthy aging in human geriatric populations (7, 10) (**Figure 1**). The concept of vigor is logically translatable to aging dogs, but there lacks a validated process to divide aging populations into the progressive categories of fun, functionality, frailty, and failure (**Figure 1**). Furthermore, unlike people, the breed and size of the dog plays an important role in suggesting the onset of old age with most giant breeds defined as geriatric at 7 years while small breeds take up to 12 years (11, 12). For an individual within any age and canine size cohort, the natural aim would be to maximize the vigor score.

Task Dependent Movement

Improving functional movement remains at the heart of a canine rehabilitation program. In fact, Hua and colleagues (3) created a canine frailty score based on similar human indices, engaging five components (under-nutrition, exhaustion, low

TABLE 1 | Variables affecting healthy aging in dogs.

Medical care	Social/family support	Healthy lifestyle	Environmental conditions
Financial resources	Value placed on pet	Appropriate nutrition	Climate/ Season
Geographical access to veterinarian or specialist	Motivation to provide rehabilitative or nursing care	Appropriate and regular exercise	Home layout and potential obstacles or risks
Pet insurance	Physical ability to provide rehabilitative or nursing care	Mental stimulation and engagement	Human and animal interactions (positive or negative)
Temporal access (time of work, childcare, etc.) to see veterinarian	Perspectives on defining a pet's quality of life	Duties or hobbies: sporting, working, therapy, etc.	Other physical enrichment (food puzzles, territorial exploration, access to outdoors, access to shelter, etc.)
Awareness of a problem and where to seek help	Access to resources for or having education in pet care	Preventative care (vaccinations, parasite prevention, dental hygiene, etc.)	Exposure to environmental risks (smoking, pollutants, toxins, infectious or parasitic agents etc.)
Annual or biannual wellness exams			

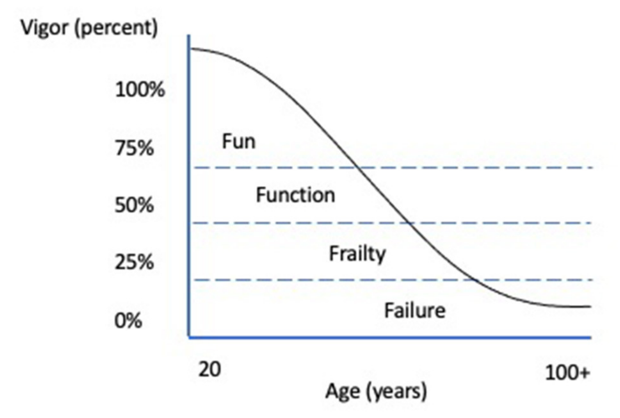

FIGURE 1 | Vigor in Aging People. Adapted from (10).

TABLE 2 | Canine task dependent movement.

Basic activity for daily independent mobility (BADIM)	Instrumental activity for daily quality of life (IADQOL)
Rising from a down position	Ascending/descending a full flight of stairs
Ambulating in and out of the home	Moving in and out of a vehicle
Posturing to eliminate	Walking short distances outside
Posturing to eat and drink	Exploring the home environment
	Interacting in play (fetch, chase, tug of war, etc.)
	Ability to navigate place of rest (couch, bed, crate, etc.)
	Maintain control of urination and defecation for 6–8 h

physical activity, poor mobility, and weakness). Poor mobility and low physical activity were both significantly correlated in time to death in this older canine population. Furthermore, a quality-of-life screening program demonstrated that increased activity was the most commonly proposed change to improve canine quality of life (13). The Katz Scale and other derived scales (such as Barthal Index and Lawson and Brody Scale) have been consistently used in human medicine since the mid 20th century to assess one's ability to function independently (14–17). Appropriate task dependent movement relies on a patient's physical abilities, cognition, and motivation. The Katz (15) scale categorizes function into Basic Activity of Daily Living (BADL) whereas Lawton and Brody (17) first identified Instrumental Activity of Daily Living (IADL). BADL includes tasks such as dressing, feeding, and bathing oneself, whereas IADL includes more complicated tasks such as house cleaning, preparing meals, shopping, and managing finances. It has been shown that as independence in function declines from IADL toward BADL, the risk of human hospitalization and death increases (14).

Similar to Katz, we have chosen to define and categorize our geriatric patient function into tasks that are required for: 1. Basic activity for daily independent mobility (BADIM) and 2. Instrumental activities for daily quality of life (IADQOL) (**Table 2**). We defined the most basic tasks for a dog to maintain independent mobility as rising from a down position; ambulating for short distances including inside and outside the home; posturing to eat or drink; and posturing to eliminate. Examples we have chosen to represent IADQOL are not comprehensive. Regardless, the proposed BADIM and IADQOL classifications aim to assist families and veterinarians into gaining better insight into patient prognosis, establishing more specific rehabilitation goals, and defining and monitoring changes in quality of life (QOL). Research would be required to define ordinal values for each activity and validate them as task dependent movement scales.

THE SYNDROME OF AGE-RELATED MORBIDITIES: SARCOPENIA, OBESITY, AND SEDENTARY LIFESTYLE

Identification and treatment of co-morbidities helps promote better responses to physiotherapy. For example, a Cushingoid dog may suffer from muscle loss, decreased endurance, and degeneration of ligament and tendon structures as part of the disease; all of which impact movement or could contribute to further orthopedic disease like cranial cruciate ligament rupture and Achilles' tendinopathy. A plethora of pathology reducing vigor in aging dogs may be sub-divided by age-related or disease-related morbidities. Three common age-related morbidities described in both human and canine medicine deserve a more in-depth discussion as they influence each other and are commonly present and respond directly to rehabilitation and exercise therapy: sarcopenia, obesity, and sedentary life style. In the experience of these clinicians, it is common to identify all three of these processes together during a geriatric exam. Furthermore, they are all highly inter-related in which an improvement or worsening of one will directly or indirectly impact the other two in similar fashion.

Sedentary Lifestyle

Subjectively measuring canine activity has proven to be challenging as most dog owners are away from home during the day and inaccurately estimate the duration and intensity of their pet's observed activity (18–20). Both accelerometers and pedometers have been used with success to provide objective data of a pet's daily activity; however, it should be noted that neither method calculates the intensity of that activity (20–23). Although these are useful tools for tracking gross activity, the data may not represent the animal's willingness or ability to exercise as environment (weather, geography, housing conditions, motivating stimuli, etc.), and owner participation/designated time may be the limiting factor. Regardless, both increasing age and increasing body condition have been negatively correlated with activity in dogs (19, 20, 23, 24). It also has been demonstrated that aging dogs, like people, tend to lose lean mass and gain adipose tissue as their metabolic rates decrease (25, 26). Exercise, combined with an appropriate diet, can help combat these changes and potentially delay or reduce the rate of their progression (26, 27). Dogs lacking mobility are predisposed to unwanted sequela including decubital sores, urinary tract infections, skin infections, and pneumonia (28, 29). For these patients, appropriate nursing care, treatment, monitoring, and environmental changes (well-padded clean bedding, floor traction, etc.) are required.

Sarcopenia

Sarcopenia is the loss of lean mass associated with aging described in many species. It may have multifactorial components including mitochondrial dysfunction, sterile inflammation, hormonal changes, neuronal regulation, and lack of exercise stimulus underlying its pathophysiology (26, 30–32). This disease process alone has been shown to increase morbidity and mortality (3, 26, 31). Lean mass loss during aging has been recorded in dogs (31, 33, 34). Both nutritional and exercise intervention may help reduce the morbidity associated with sarcopenia. Exercise, combining strength training and aerobic activity, may provide the most benefits for both function and muscle mass for people suffering from sarcopenia (26, 30–32). Unfortunately, no such canine research has been conducted; however, Vitger et al. (35) recently demonstrated that exercise preserved lean muscle mass in dogs involved in weight loss programs. Although differences in muscle function, structure, and aerobic capacity exist between people and dogs, the strong parallels regarding sarcopenia in animals allow for reasonable inference that targeted exercise and physiotherapy should also benefit veterinary patients. Diets richer in protein, may also help ameliorate the effects of sarcopenia in otherwise healthy older dogs (36). Furthermore, it has been proposed that geriatrics have a higher protein turnover than their adult counterparts, requiring more protein in their diet to help maintain muscle (37). Therefore, consideration of the quality and quantity of protein in the diet should be optimized whenever possible, taking particular care to maintain daily protein above 3 g/kg lean mass when indicated for dogs on weight loss plans.

Obesity

It has been consistently shown that obesity decreases longevity and increases morbidity in dogs (19, 23, 26, 27, 38–41). The effects of weight gain on mobility includes exacerbation of osteoarthritis; while weight loss in this canine population has been associated with reduced lameness (42, 43). Furthermore, dogs suffering from obesity that are otherwise healthy, like people, have increases in weight bearing forces and different ranges of motion in their appendicular joints (44). To these authors' knowledge, there has not been research demonstrating worse ambulation or function in obese dogs suffering from neurological disease than those that are lean. However, obesity certainly appears to increase the physical effort and emotional fatigue when rehabilitating non-ambulatory dogs affected by paresis or plegia, both in the clinical setting and in terms of compliance with home care. For example, euthanasia rates are higher for dogs suffering from fibrocartilaginous embolism when they are larger (45). Additionally, geriatric populations may recover more slowly from spinal cord injury (46). Regardless, combatting obesity with appropriate nutritional and exercise intervention can improve movement function, decrease discomfort, and help retain lean muscle mass in aging dogs (27).

THE DISABLEMENT MODEL FOR GERIATRIC ASSESSMENT, TREATMENT, PROGNOSIS, AND MONITORING

In human medicine multiple models have been developed to both identify and characterize disablement at various levels, most often from the origin, organ/system level, individual person level, and societal/environmental level (47). The benefits of using disablement models include standardizing communication amongst healthcare professionals, providing a contextual framework for directing care based on the unique needs of the patient, and providing an objective tool for research regarding the efficacy and effectiveness of treatments (47, 48). In 1965, the Nagi Disablement Model was developed for humans to describe the impact disease and injury have on an individual at both the level of the person and the level of society (47, 48). The model has four dimensions: active pathology, impairment, functional limitations, and disability. Active pathology is described at the cellular level and defined as damage to the integrity of a body structure. Impairment is described as the abnormality at the

TABLE 3 | Nagi model applied to a law enforcement canine patient with a grade II/III iliopsoas tendinopathy.

Dimension of model	Level of disablement	Patient example
Active pathology	Cellular	Grade II/III iliopsoas tendinopathy
Impairment	Body systems	Decreased strength of the iliopsoas, pain upon iliopsoas stretch, decreased flexion/extension of the spine and pelvis
Functional limitations	Whole patient	Inability to extend spine and pelvis when pushing off hind limbs for apprehension work
Disability	Patient's relation to society	Inability to perform apprehension work as K-9 officer

tissue, organ, or body system level and includes clinical signs and symptoms. Functional limitations refer directly to the person and are defined by restrictions in performance at the level of the whole person, particularly in relation to the patient's social roles and daily activities. Finally, disability is defined as the inability of the person to fulfill their desired or necessary social or personal roles. If one were to apply this model to a canine patient, **Table 3** would be a comparable example for a law enforcement K-9 unit who has sustained a grade II/III iliopsoas tendinopathy (**Table 3**).

FUNCTIONAL TESTING

Objective methods of monitoring patients are most desirable as they provide a more concrete assessment and prognosis as well as follow up. Many types of objective methods have been previously described elsewhere for dogs and may include muscle girth, kinetic or kinematic gait analysis, weight bearing at a stance, goniometry, and accelerometry/pedometry (49–54). Despite the importance of task dependent movement/function for both owners and veterinarians, a paucity of literature exists in dogs. Measuring and defining function through clinical examination and patient history remains essential to the disablement model process of developing individually targeted physiotherapy. In canine patients, functional limitations are a product of impairment, which can be a decrease in strength, endurance, mobility, balance, proprioception, flexibility, and/or range of motion. Within this context we have reviewed the pertinent canine and human literature; highlighted several methods to examine canine geriatric task dependent movement (within the hospital setting); and proposed a reasonable, testable framework for developing a standardized canine geriatric functional score.

Strength

In humans, multiple functional tests have been developed as a measure of strength. Decreased strength has been found to correspond to frailty and sarcopenia (55, 56). It has also been correlated to increased risk of fall, morbidity, death, increased hospital stays, and increased hospitalization cost (57–62). The Grip Strength test is a commonly used screening tool that quantifies the maximum force generated by the patient's forearm musculature using a hand-held dynamometer. Unfortunately, this strength test is not applicable to most animals.

Commonly used strength tests to assess lower body strength in humans are the 30 second chair stand test, or the Five Times sit-to-stand (5xSTS). Poor performance on either test has been associated with increased frailty, disability, falls, fractures, and mortality (63–70). Such methods are relatively easy to translate to dogs; however, as dogs are quadrupeds, a more appropriate test may be a sternal recumbent to rise as it engages all weight bearing limbs more equally than a sit to stand (**Table 4**).

Finally, in human medicine manual muscle testing is used to assess strength on a 1–5 rating scale. These tests require the patient to apply resistance through a body part at different points of range of motion (71) and therefore cannot be applied to dogs. Various forms of canine muscle tests have been described to assess baseline isometric strength in a standing position, such as a timed 3-leg stand (53); however, none have been validated yet. Implementation of such a test in a standard fashion could prove complicated given the uneven distribution of weight between the forelimbs and hindlimbs of a dog.

Endurance/Mobility

The 6-min walk test was developed to assess mobility and endurance, measuring the distance achieved at a quick walk over 6 min. The 6-min walk test has been used for patients with congestive heart failure, chronic pulmonary disease, and peripheral occlusive arterial disease (72–74). This test was validated to differentiate the difference between healthy dogs and dogs with pulmonary disease (75). Similar outcome measures could be applied to geriatric dogs; however, the duration and physical area required render it less appealing for routine testing.

The "Timed Up and Go" (TUG) Test has been developed to assess human mobility. The patient is observed and timed while they rise from an armchair, walk 3 meters, turn, walk back to the chair, and sit down again. People exceeding 12 s to complete this test are at a greater risk for fall (76–78). While this test has not been validated for dogs, we propose a readily adapted version (**Table 4**). One would ask the dog to rise from a sternal recumbent position and move 10 body lengths forward at the quickest manageable gait on or off leash. Rising from a sternal position tests weight bearing limbs more evenly than from a sit; furthermore, simplifying the task as a straight line helps reduce variation in following instructions.

Lastly, ratings of perceived exertion (RPE) are used to assess human endurance and conditioning. They are based on an individual's perception of difficulty to perform an exercise or task. These scales have been developed and validated in both adults as well as young children, who often are unable to consistently communicate their feelings regarding exercise (79). Recently a

TABLE 4 | Canine geriatric functional score tests in order to be administered to patient.

Test	Test description	Scoring	Score description
A			
TUG–timed up and go	Rise from down sternal position and move straight (+/– leash) 10 body length units on flat ground with good footing at quickest manageable gait	0	Incapable
		1	> 15 s
		2	>10–15 s
		3	>5–10 s
		4	≤ 5 s
B			
Cavaletti	Walk on leash two rails at hock height, body length apart (nose to rump), two rails, two passes (once in each direction) for a total of four rails	0	Incapable
		1	Major contact, navigates slowly with extreme difficulty
		2	Moderate contact, partial gait adjustment
		3	Some contact, adjusts gait accordingly, completes task
		4	Minimal to no contact, navigates well
C			
Figure 8's	Figure 8 with diameter of body length for four complete repetitions on leash at a walk	0	Incapable without falling
		1	Consistent knuckling, heavy crossing over, scuffing, delayed pivot
		2	Occasional knuckling, mild to moderate crossing over, scuffing, delayed pivot
		3	Abnormal or delayed pivot (no falls), +/– scuffing
		4	Completes without abnormal crossing over or tripping
D			
Down	Sternal to rise until failure within a 60 s period (manual assistance to reposition in sternal allowed)	0	Incapable
		1	≤5 reps
		2	>5–10 reps
		3	>10–15 reps
		4	>15 reps

Final Summed Score	Description
0–4	Poor
5–8	Fair
9–12	Good
13–16	Excellent

perceived exertion scale (PES) was validated for canine patients and shown to correlate with measured physiologic parameters (80). Dogs were asked to exercise on a treadmill at various intervals for a total time of 55 min. The perceived exertion was recorded every 2 min and rated on a scale of 0 to 4 (**Table 5**). The study concluded that the PES exhibited consistent and repeatable use when monitoring healthy dogs exercising on a land treadmill at mild to moderate intensity, but that further validation would be required for patients suffering from orthopedic or neurologic disease (80). Such a scale could be easily applied to canine patients receiving regular underwater treadmill therapy when controlling for speed, water height, and inclination by body

TABLE 5 | Canine perceived exertion scale.

Grade	Exertion level	Description
0	No effort noted	No signs of exertion, panting (increased/change in panting), agitation, or abnormal gait
1	Comfortable	May be showing early signs of exertion, very early panting, no to minimal agitation, no change in gait
2	Light effort	Moderate signs of exertion, panting consistently but not labored breathing, mild agitation, no change in gait
3	Moderate effort	Obvious signs of exertion, hard panting, mild labored breathing, moderate agitation, moving slow or reluctantly
4	Significant effort	Obvious signs of exertion, panting very hard, moderate labored breathing, occasional stumbling (< 35%)

TABLE 6 | Validated client surveys for canine pain and quality of life assessment.

Canine brief pain inventory (CBPI) (81)
Helsinki chronic pain index (HCPI) (82)
Canine orthopedic index (COI) (83–85)
Liverpool osteoarthritis in dogs (LOAD) (86)
Visual analog scale (VAS) (87)
Glasgow composite measure pain scale short form (CMPS-SF) (88)
Canine health related quality of life survey-21 (CHQLS-21) (89)
Canine osteoarthritis staging tool (COAST) (90)

size. Therefore, we propose walking with the water height at hip level over flat terrain as the best and most accommodating standard test, while applying the same perceived exertion scale as Swanson and colleagues (80). It should be highlighted that results of geriatric dogs partaking in this test may further be confounded by factors beyond conditioning such as pain or neurological status. Unlike Swanson's PES, our proposed test will time a patients' ability to walk before reaching a perceived "moderate effort". Such a proposal would limit availability to those veterinarians with an underwater treadmill and therefore is less practical or broad reaching when considering development of a standardized universal test. However, further research is warranted to determine if it stands as a valuable tool for some clinicians.

Balance/Proprioception

Coordination and proprioception are known to decline in aging human and canine patients. Often a decrease in proprioception and loss of muscle strength can lead to an increased risk for falls and disability (91). In human medicine, several aspects of balance are assessed and categorized into static steady-state balance (maintaining a steady position while sitting or standing), dynamic steady-state balance (walking), proactive balance (anticipating a predicted disturbance such as walking around an obstacle), and reactive balance (compensating for a disturbance) (92). Numerous functional tests have been validated in humans for assessing one or multiple aspects of balance.

The Unipedal Balance Test (UBT) is used to assess static steady-state balance in human patients (93, 94). Another validated and reliable assessment tool for functional balance is the Berg Balance Scale (BBS) with 14 different scaled markers (95, 96). The Dynamic Gait Index (DGI) was developed and validated to assess dynamic balance, rating the ability of the patient to balance while walking and performing eight different tasks (97–100). Finally, the BESTest and Mini-BESTest (shortened version) were developed to assess multiple aspects of balance. The BESTest contains 36 tasks for evaluating 6 different balance control systems, including biomechanical constraints, stability limits with verticality, anticipatory postural adjustments, automatic postural responses, sensory organization, and stability in gait (101). There are currently no validated balance and spatial awareness tests for canine patients. Although three-legged standing tests have been described and are commonly used in rehabilitation practice to assess a canine's strength and steady-state balance (53); this test has a complexity that would likely exclude it from being easily replicated, quantified, or broadly employed. On the other hand, we believe that walking Figure 8's and step over Cavaletti rail obstacles test both the feedforward and feedback systems necessary to judge dynamic balance and spatial awareness with a higher degree of objectivity and less variability amongst patients and practitioners (**Table 4**).

Canine Geriatric Functional Score

Similar to human medicine, we believe there remains a dire need to have a validated, practical, and meaningful task-based functional scoring system for our geriatric patients. The Canine Geriatric Functional Score is an assessment tool we are developing to provide an overall measure of function by testing strength, endurance, and balance/spatial awareness through 4 different sequential standardized tasks. The tests should be replicated in a specific order at the beginning of an appointment, as preceding tasks impact latter ones. This assessment is currently undergoing validation trials but can be accomplished in most dogs with relative ease, minimum personnel (two people), and a short time frame (5 min) (**Table 4**).

ESTABLISHING REASONABLE AND ACHIEVABLE REHABILITATION GOALS

By engaging the Nagi model, short-term and long-term goals can be derived to address a patient's impairments and functional limits. These goals may need to be modified for the client based on the same variables that effect healthy aging (**Table 1**). For many geriatric dogs, it is important for clients to understand that patients often will make improvements initially and reach their shorter-term goals; however, other times the rehabilitation process must adjust to maintain such improvements or even reduce the rate of decline. A thorough patient assessment and understanding of optimal aging, can provide the clinician with tools to best convey expectations to owners. Furthermore, appropriately timed follow up remains essential for monitoring patient health status and function and adjusting goals accordingly. As a patient moves into the end stages of life, the rehabilitation specialists should work closely with the family and medical team to identify and establish appropriate quality of life goals, provide palliative and nursing care options, or consider euthanasia.

MONITORING PROGRESS AND REASSESSMENT

Once the Disablement Model has been applied to the geriatric patient, a plan should be made to reach the listed goals within prescribed timeframes. As the canine geriatric patient often has multiple co-morbidities, a team approach (rehabilitation therapist, primary care doctor, other medical specialists, and family) with clear communication is key for successful management.

We recommend initiating more frequent follow ups of the geriatric patient which could include:

- Professional reassessment every 4–6 weeks followed by adjusting the goals and physiotherapy accordingly.
- Baseline and periodic health screening including complete blood count, biochemistry panel, and urinalysis as well as any indicated monitoring or follow-up lab work for metabolic disease or NSAID use.
- Weight and body composition monitoring every 4–6 weeks.
- Regular professional rehabilitative therapy (once to twice weekly when feasible) +/– interventional pain management (such as therapeutic injections, acupuncture, modalities) as indicated.
- A combination of Objective and Subjective Assessment Strategies should be employed.

Consideration in balancing professional clinical rehabilitation with home exercise therapy must be weighed and is often influenced by similar variables to those affecting healthy aging. For example, cost and distance were the two variables most likely to prevent referral of a client seeking a rehabilitation specialist for the pet (102). On the other hand, a study examining outcomes from T3-L3 hemilaminectomies in dogs noted that those receiving rehabilitation had fewer post-operative complications, further supporting the notion that professional physiotherapy allows for closer patient monitoring and timelier intervention (103).

Objective Assessment Strategies

As reviewed, there are multiple objective assessment strategies the clinician can employ to assess a patient on site. Commonly applied objective assessment strategies used in a clinic setting may include muscle girth, kinetic or kinematic gait analysis, weight bearing at a stance, and goniometry (49–54). It is important to perform these objective assessments at baseline and then every 4–6 weeks (or sooner if there is a change in the patient's status). Collecting the objective measures often may depend on efficiency and availability of materials or trained staff. While objective assessments present a greater challenge to the client at home, monitoring task specific progress is helpful and may include their prescribed home exercise program such as: minutes of leash walking before fatigue, number of sit to stands a patient is able to do in a row or in 30 s, and time the patient is able to hold a 3-legged standing position. Canine digital health monitors may grow in popularity and provide additional information but should be interpreted within context by a professional.

Subjective Assessment Strategies

The subjective assessment of the patient is often easier for the client to understand, and the information shared is potentially more important to the client. There are a number of validated client specific outcome measure (CSOM) surveys to assess pain and quality of life (**Table 6**). We engage these surveys for research and occasionally for clinical follow up; however, many clients find them tedious. Despite CSOM value, families also wish to directly discuss how they perceive the patient is doing at home and often have similar markers for their patient assessment. Clients often emphasize the patient's eagerness to move at home or task specific ability such as rising out of bed, roaming the house, navigating out of the home, posturing to eliminate, play, maintaining better traction (reduced slip or fall), and jumping on the bed or into the car. It is important to remember that the family's perspective is vital when determining and discussing quality of life. Ideally a validated task dependent movement scale (such as the proposed BADIM and IADQOL) for companion animals will assist in this process.

CONCLUSIONS

The veterinary field lacks standardized scoring systems to assess and better manage an expanding population of geriatric canine patients. Because geriatrics often suffer from mobility issues related to the diseases or processes of aging, they require comprehensive rehabilitative care to optimize their health. Mobility and task specific function are vital to the quality of life in dogs and are prognostic to hospitalization and death in people. Although tools to assess the human patient population have been employed, none are specific to canine geriatrics and none objectively measure function. The complexity of comorbidities associated with aging dogs demands strong communication amongst the care team and family as well as collaborative goal formulation and close follow up. Therefore, we found it imperative to review the available literature; provide a foundation for canine geriatric assessment, goal setting, and follow up; and propose a testable framework for geriatric specific functional scoring. Furthermore, we hope this review springboards ideas for canine geriatric specific rehabilitative research.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Static Body Weight Distribution and Girth Measurements Over Time in Dogs After Acute Thoracolumbar Intervertebral Disc Extrusion

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Dogs with thoracolumbar intervertebral disc extrusion (TL-IVDE) can exhibit variable neurologic deficits after decompressive surgery. The objectives of this study were to quantify changes in static weight distribution (SWD) and limb and body circumference over time in dogs recovering from surgery for TL-IVDE. Dogs with acute TL-IVDE were prospectively evaluated at baseline (48–72 h post-operatively), 2, 4, 8, and 12 weeks post-operatively. Commercially-available digital scales were used to measure weight distributed to the pelvic limbs (PL%) and asymmetry between left and right pelvic limbs (LRA), each expressed as a percentage of total body weight. Trunk and thigh circumference measurements were performed using a spring-loaded tape measurement device. Measurements were performed in triplicate, compared to neurologically normal small breed control dogs and analyzed for changes over time. $P<0.05$ was significant. Twenty-one dogs were enrolled; 18 regained ambulation and 3 did not by study completion. PL% increased from 27.6% at baseline to 30.7% at 12 weeks but remained lower than in control dogs (37%) at all time points ($p < 0.0001$), even excluding dogs still non-ambulatory at 12 weeks ($p < 0.025$). LRA was similar to the control dogs, and did not have an association with surgical side. Caudal trunk girth decreased over time to 95% of baseline ($p = 0.0002$), but this was no longer significant after accounting for reductions in body weight ($p = 0.30$). Forward shifting of body weight persisted in dogs with TL-IVDE 12 weeks after surgery even among ambulatory dogs. SWD and circumference measurements could provide additional objective measures to monitor recovery.

Keywords: canine, disc herniation, spinal cord injury, digital scales, chondrodystrophic, body weight

INTRODUCTION

Acute spinal cord injury (SCI) secondary to thoracolumbar intervertebral disc extrusion (TL-IVDE) in dogs can result in persistent neurologic deficits, even among dogs who regain independent ambulation. Residual functional abnormalities that have been reported in some dogs include deficits in coordination of limbs or between limbs and forward shifting of the center of pressure (1–4).

Digital scales have been used to evaluate pelvic limb static weight distribution (SWD) in dogs (5–7). In neurologically normal, chondrodystrophic small breed dogs, a mean of 63% of total body weight was borne by the thoracic limbs with a mean of 37% on the pelvic limbs (5), which is comparable to healthy large breed dogs in which 64% of body weight was placed on the thoracic limbs (7). This method was noted to be reliable and useful in dogs with osteoarthritis undergoing rehabilitation (6) but has not been explored in dogs with TL-IVDE.

Pelvic limb circumference measurements have also been reported in dogs (8–12). Thigh girth measurements were noted to be a potentially useful outcome measure in dogs with stifle disease (8) though reliability was highlighted as an issue and underscored the need to perform measurements under standardized conditions (8, 9, 11). In Dachshunds with acute TL-IVDE, thigh girth measurements were not associated with the severity of pelvic limb weakness, though measurements were only performed once at the time of initial presentation (12). When dogs with TL-IVDE were evaluated for 6 weeks post-operatively as part of a randomized clinical trial investigating rehabilitation, 80% of dogs had mild weight loss and mild decreases in thigh circumference over the first 2 weeks that largely returned to baseline by study end (13). Using a DEXA scanner in a group of Dachshunds managed surgically for TL-IVDE followed by postoperative rehabilitation, a reduction in body weight (2.2 kg), small decrease in body fat (2.4%) and increased lean muscle mass (3%) were demonstrated by 12 weeks postoperatively compared to baseline, though the majority of the dogs enrolled were overweight and specific girth measurements were not performed (14).

The SWD between thoracic and pelvic limbs and left and right pelvic limbs is unknown in dogs after acute TL-IVDE. Furthermore, it is also unknown how weight distribution changes over time, how this relates to recovery of ambulation and how this impacts musculoskeletal changes after SCI. It is possible that alterations in weight distribution could reflect and exacerbate residual pelvic limb weakness after severe SCI. Measuring such changes over time might capture persistent abnormalities and provide objective rehabilitation targets to enhance overall recovery and guide rehabilitation practices and recommendations during the post operative recovery period.

Abbreviations: TL-IVDE, thoracolumbar intervertebral disc extrusion; SCI, spinal cord injury; SWD, static weight distribution; OFS, open field scale; PL%, pelvic limb static weight distribution as percentage of total body weight; LRA, left right asymmetry between pelvic limbs; aLRA, absolute left right asymmetry between pelvic limbs.

TABLE 1 | Gait scores for each study visit.

Study visit	Median (range) OFS		
	All dogs	HF dogs	LF dogs
Baseline	2 (0–6)	2 (0–6)	0 (0)
2 week	6 (0–9)	7 (2–9)	0 (0–1)
4 week	9 (1–12)	9 (5–12)	1 (1–3)
8 week	9 (1–11)	9 (7–12)	2 (1–4)
12 week	10 (1–12)	11 (8–12)	2 (1–5)

OFS, open field score (0–12); HF, high functioning group (OFS ≥ 7 by 12 weeks or sooner), LF, low functioning group (OFS < 7 by 12 weeks).

TABLE 2 | Pelvic limb static weight distribution as a percent of total body weight (PL%) at each study visit.

Study visit	Mean (SD) PL%		
	All dogs	HF dogs	LF dogs
Baseline	27.6 (6.5)	27.3 (6.6)	NA
2 week	29.1 (4.6)	29.4 (4.7)	26.4 (1.0) (*n* = 2)
4 week	29.0 (5.4)	29.2 (5.6)	26.9 (2.5) (*n* = 2)
8 week	30.1 (5.2)	30.3 (5.5)	28.8 (1.2) (*n* = 2)
12 week	30.7 (5.1)	30.7 (5.0)	30.8 (7.4) (*n* = 3)

HF, high functioning group; LF, low functioning group.

The aims of this study were: to quantify SWD and pelvic limb and trunk circumference longitudinally in dogs treated surgically for acute TL-IVDE. We hypothesized that dogs with TL-IVDE would show an initial forward shifting of body weight and increased asymmetry between left and right pelvic limbs when compared to a similar population of healthy control dogs. We further hypothesized that SWD would normalize as motor function improved and that muscle mass loss would be minimal during the study period.

MATERIALS AND METHODS

Study Animals

Dogs with acute TL-IVDE were prospectively recruited from the existing patient pool of Purdue University Veterinary Hospital. To be included, dogs had to weigh ≤ 20 kgs, be between 1 and 10 years old, and be diagnosed with acute TL-IVDE (spinal segments T3-L3) leading to non-ambulatory paraparesis or paraplegia with or without pain perception. Duration from the onset of neurological deficits to enrollment had to be ≤7 days. All dogs were diagnosed via computed tomorgraphy or magnetic resonance imaging, treated with decompressive hemilaminectomy and managed post-operatively at the discretion of the clinician in charge. This included basic post-operative rehabilitation exercises during hospitalization in all dogs. Dogs with concurrent orthopedic conditons were excluded. Owners gave informed consent, and procedures were conducted in accordance

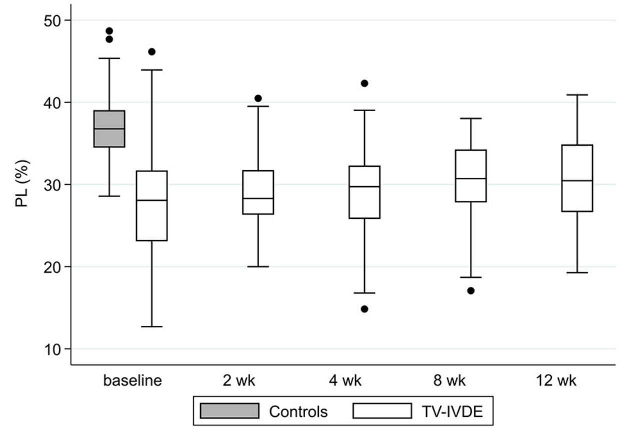

FIGURE 1 | PL% in normal and TL-IVDE dogs at baseline and across study visits. PL%: pelvic limb static weight distribution as a percentage of total body weight.

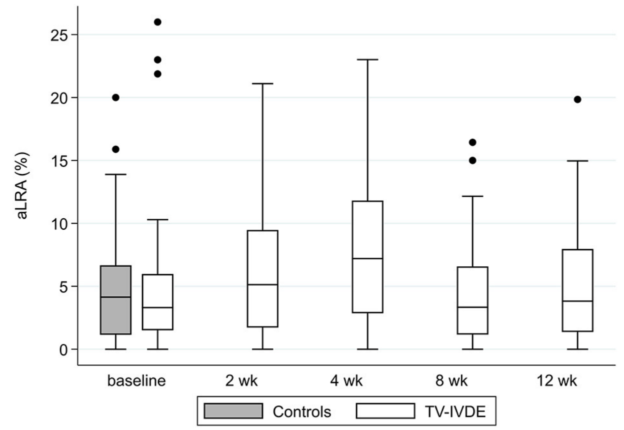

FIGURE 2 | Absolute LRA for each study visit in dogs with TL-IVDE compared to healthy control dogs. aLRA: absolute left right asymmetry between left and right pelvic limbs.

to Purdue Institutional Animal Care and Use Committee (protocol #1804001743). Study dogs were compared to a previously published group of neurologically and orthopedically normal adult chondrodystrophic dogs used to develop our methods (5).

Study Procedures

The procedures outlined were performed at baseline and at re-check visits at 2, 4, 8, and 12 weeks after initial hospitalization. The baseline visit occurred during initial hospitalization between 48 and 72 h after surgery. This ensured dogs no longer needed intravenous pain medication and increased the likelihood of being amenable to handling and successful data acquisition. All follow up visits were performed on an outpatient basis. All owners were instructed to peform daily basic rehabilitation exercises at home for the first 4–6 weeks following discharge, as is standard of care at our hospital. These included passive range of motion and massage, assisted standing and assisted walking. Owners could elect to participate in additional outpatient rehabilitation, but this was not specifically recommended and no specific instructions or goals of such therapy were provided.

Standard Neurologic Examination and Gait Evaluation

Dogs underwent complete neurological examination including evaluation of gait, proprioception, spinal reflexes and pain perception. Dogs were videotaped walking on a flat, non-slip surface with gait deficits scored using a validated open field scale (OFS) ranging from 0 to 12 (15, 16) by two authors (NAM, MJL). Scores of 7 and above reflect the ability to take weight bearing steps 100% of the time. Using OFS scores, dogs were classified as high-functioning (HF, OFS $\geq$ 7 by 12 weeks or sooner) or low-functioning (LF, OFS $<$ 7 by 12 weeks).

Body Weight Distribution

Static weight distribution was determined using commercially available, factory-calibrated digital bathroom[1] (range 1.4 to 200 kg, 0.1 kg accuracy) or kitchen scales[2] (range 1 g to 5 kg, 1 g accuracy) as previously described (5). Briefly, dogs were placed in a standing position, with each limb centered on an individual scale or, separately, with each pair of limbs (thoracic or pelvic) centered on a scale (**Supplementary Figures 1, 2**). A trial was considered successful when a dog stood still and unassisted for at least 3 seconds, with their head facing forward. Dogs were allowed to acclimate to standing on the scales for several minutes before measurements began. This included being able to explore the scales, interact with the handlers and being placed in a standing position several times. Testing was then performed in a quiet environment free from distractions. Dogs unable or unwilling to stand unassisted were not included in analysis for that method at that timepoint. All scale measurements were acquired in kilograms and performed in triplicate with brief breaks between each acquisition.

Using two bathroom scales, pelvic limb SWD (PL%) was defined as the weight borne by the pelvic limbs as a percentage of total body weight. Using four kitchen scales, the weight distributed to left or right pelvic limbs was also expressed as a percentage of total body weight (LH% or RH%, respectively). For dogs above the weight range for the kitchen scales (>5 kg for an individual limb), four bathroom scales were used to capture data on left and right limbs individually. Left to right asymmetry (LRA) of pelvic limbs was defined as the difference between RH% and LH%. For a given visit, the following definitions of LRA were utilized:

- Values $\geq$ 5% were considered "leaning right" (i.e. bearing more weight on the RH),

[1]Smart Weight Smart Tare Digital Body Weight Bathroom Scale, amazon.com.
[2]ETEKCITY Digital Kitchen Scale, Model No EK6212-S, amazon.com.

TABLE 3 | Absolute LRA for each study visit.

Study visit	Median (range) aLRA %
	All dogs
Baseline	4.0 (0.7–26.0)
2 week	6.0 (0.2–21.1)
4 week	7.6 (1.0–23.0)
8 week	4.8 (0.7–16.4)
12 week	4.9 (0.8–19.8)

aLRA, absolute left right asymmetry between left and right pelvic limbs.

TABLE 4 | Mean thigh and body circumference measurements as a percentage of baseline values.

Study visit	Left thigh girth % (SD)	Right thigh girth % (SD)	Cranial trunk girth % (SD)	Caudal trunk girth % (SD)	Caudal trunk girth to body weight % (SD)
Baseline	100	100	100	100	100
2 week	97.7 (9.0)	97.7 (11.5)	99.8 (4.1)	95 (4.8)	98.2 (4.4)
4 week	103.9 (13.5)	106.9 (15.8)	99.2 (3.9)	92.8 (7.1)	96.8 (4.6)
8 week	100.6 (12.0)	103.5 (12.0)	99.4 (4.4)	95 (7.6)	98.3 (6.2)
12 week	103.6 (13.8)	105 (16.8)	99.3 (3.8)	94.4 (6.0)	98.2 (5.3)

- Values $\leq -5\%$ were considered "leaning left" (i.e. bearing more weight on the LH)
- Values between -5% and 5% were categorized as "no lean"

Dogs were then classified overall as follows:

- "Leaning right" if LRA exceeded 5% on at least one visit
- "Leaning left" if LRA was <-5% on at least one visit
- "No lean" if LRA was between −5 and +5% for all visits
- "Both" if LRA was >5% and <-5% on separate visits

To evaluate asymmetry between pelvic limbs irrespective of direction, absolute LRA (aLRA) was defined as the absolute value of the LRA between pelvic limbs.

Body and Limb Circumference Measurements

Using a Gulick type II spring-loaded tape measurement device[3], right and left thigh, cranial trunk, and caudal trunk girth measurements were performed (**Supplementary Figure 3**). While dogs were lying in lateral recumbency, hind limb circumference of the upper leg was measured at 50% of the thigh length from the greater trochanter to the distal femur (12, 17). Trunk measurements were performed in a standing position. Cranial trunk girth was measured around the rib cage, immediately caudal to the thoracic limbs, while caudal trunk girth was measured around the abdomen just cranial to the inguinal folds. All measurements were made in triplicate by one of two authors (JB or ST). To account for variations in size and weight between dogs, all circumference measurements for follow up visits were expressed as a percentage of the baseline value (100%).

[3]Gulick II Tape Measure, Fitness Mart, GaysMills, WI.

Statistical Analysis

Summary statistics are reported as mean (standard deviation) or median (range), for parametrically or nonparametrically distributed data respectively, based on a Shapiro-Wilk test for normality. Analysis for statistical significance was performed using SAS PROC MIXED mixed linear effects model for repeated measures with *post-hoc* Bonferroni adjustment for multiple comparisons; statistical significance was defined as $p < 0.05$.

Mean PL% of TL-IVDE dogs at each visit was compared to mean PL% for the healthy control dogs (5). Excluding the LF dogs ($n = 3$, OFS<7 by 12 weeks) who did not recover ambulation in the typical timeframe, PL% of the HF dogs at each visit was also compared to PL% for the control dogs. For all TL-IVDE dogs, changes in PL% over time were assessed in the mixed effects model with dog as a random effect. Pearson correlation coefficient was calculated to evaluate the relationship between PL% and OFS at each visit.

A Fisher's exact test was performed to evaluate the association between dogs classified as leaning right or leaning left and the side of hemilaminectomy (right or left). Dogs categorized as "no lean" or "both" (i.e. "leaning left" and "leaning right" on separate visits), were excluded from the analysis. Absolute LRA was compared between the control dogs and TL-IVDE dogs for each visit, assessing changes in asymmetry of pelvic limbs over time.

Circumference of left and right pelvic limbs, cranial trunk girth, and caudal trunk girth were analyzed for changes over time using analysis with baseline data compared to follow up visits. To account for changes in overall body weight over time, measurements were expressed as a ratio by dividing by total body weight.

RESULTS

Study Population

Twenty one dogs were enrolled in the study: nine Dachshunds, two Maltese, one Pekingese, one Lhasa Apso, one French Bulldog, one Cocker-Spaniel, and six chondrodystrophic mixed breed dogs. There were eleven males and ten females, with a mean age of 5.4 years (SD 2.4) and mean body weight of 7.4 kg (SD 2.7). The mean body weight of the TL-IVDE dogs in this study was significantly lower than the healthy control dogs used for comparison (mean body weight: 12.1 kg, SD 3.28, $p < 0.0001$), though the age and breed distribution were similar (5). At baseline, 14 dogs were non-ambulatory paraparetic, four were paraplegic with intact pain perception, and 3 were paraplegic without pain perception.

The mean time interval between the onset of neurological signs to decompressive surgery was 38 h (SD 20), and the mean time interval from onset of neurological signs to enrollment in the study was 4 days (SD 1). Of the 21 dogs, 16 completed all visits. Twenty dogs completed a 2 week visit (±5d), 20 dogs had a 4 week visit (±5d), 17 dogs had an 8 week visit (±5d), and 18 dogs had a 12 week visit (±14d). All dogs participated in basic post-operative rehabilitation during initial hospitalization and were instructed to continue to perform passive range of motion, massage, assisted standing and assisted walking at home until they were walking or the 4-week recheck. Two dogs participated in outpatient rehabilitation programs (at other hospitals) and specific details or exercise regimens were not available.

Gait Scoring

Table 1 outlines the OFS for each study visit. Eighteen dogs were categorized as HF (OFS score of $\geq$ 7 by 12 weeks or sooner); 10/18 achieved this score by 2 weeks, 5/18 by 4 weeks, and 3/18 by 8 weeks. Three dogs did not recover ambulation by 12 weeks and were designated as LF. Two of the LF dogs were initially deep pain negative and did not regain pain perception in the duration of the study, while the third was initially paraplegic with blunted but intact pain perception.

Pelvic Limb Static Weight Distribution

Mean PL% at each visit is summarized in **Table 2** and **Figure 1**. Three dogs were unable to meet the definition of standing at baseline (2 LF, 1 HF), and 1 of these LF dogs was also unable to stand at the 2, 4 and 8 week visits. These dogs were not included in summary data for these visits. Values generally increased over time ranging from 27.6 to 30.7% but the differences we not significant after adjusting for multiple comparisons ($p = 0.26$). Compared to the mean PL% of 37% reported in the control dogs (5), the mean PL% of all TL-IVDE dogs was significantly lower at all timepoints ($p < 0.0001$). When just considering the HF group, PL% was still significantly lower than in the control dogs at each visit ($p < 0.025$). Open field scores and PL% were moderately correlated at each visit ($r = 0.50$, $r^2 = 0.25$, $p < 0.0001$).

Asymmetry Between Left and Right Pelvic Limbs

Eleven dogs had LRA $\geq$ 5% were classified as "leaning right." In 7/11 dogs this was noted at a single timepoint while 4 dogs were noted to lean to the right at 2 to 4 study visits. Two dogs had LRA $\leq$-5% and were classified as "leaning left," both of which leaned to the left on 3 occasions. Four dogs were classified as "no lean," 3 dogs had LRA values $< -5\%$ and $>5\%$, and individual limb data was not available in one dog precluding determination of LRA. Eleven of the 13 dogs (85%) that were classified as leaning left or right during their recovery bore more weight on the pelvic limb opposite from the side of surgery, though the relationship between surgery side and the direction of leaning was not significant ($p = 0.077$).

Absolute left right asymmetry (aLRA) for all dogs across study visits ranged from 0.2 to 26.0%(median 5.1%), compared to a median of 4.9% (0.5–20.0%) in the healthy control dogs (**Table 3**; **Figure 2**). No significant differences were identified in aLRA between the control dogs and TL-IVDE dogs at any visit ($p = 0.079$). Among the TL-IVDE dogs, asymmetry between pelvic limbs was greatest at the 4 week visit but no significant changes over time were noted ($p = 0.17$).

Body and Limb Circumference Measurements

Limb and trunk circumference measurements are summarized in **Table 4**. Mean right and left thigh circumference as a percentage of baseline measurements showed a slight decrease at 2 weeks but were the same to mildly higher than baseline values at all other study visits (**Figures 3A,B**). Changes over time for right and left thigh circumference were not significant ($p = 0.0821$, $p = 0.29$). Cranial trunk girth as a percentage of baseline measurements demonstrated minimal change across study visits ($p = 0.95$) (**Figure 3C**). Caudal trunk girth significantly decreased over time ($p = 0.0002$) with the greatest decrease at the 4 week visit of nearly 8% (**Figure 3D**). Compared to baseline, caudal trunk girth was significantly decreased at weeks 2, 4 and 12 weeks ($p < 0.038$). Caudal trunk girth expressed as a ratio of total body weight was still lower at follow up visits compared to baseline but the differences were no longer significant ($p = 0.30$).

DISCUSSION

Dogs with acute TL-IVDE treated with decompressive surgery demonstrated altered body weight distribution during the recovery period. While weight distributed to their pelvic limbs increased over time, it did not normalize by 3 months post-operatively when compared with values in neurologically normal, chondrodystrophic small breed dogs. Changes in girth measurements during the study period were small and impacted by variability, but forward shifting of weight could have contributed to reductions in hindquarter muscle mass. Asymmetry in weight distribution between left and right pelvic limbs was similar to asymmetry present in normal dogs and lacked clear trends over time.

Our results demonstrated that dogs with acute TL-IVDE managed surgically leaned forward during their recovery. Compared to a group of neurologically normal, healthy small breed dogs that bore 37% of total body weight on their pelvic limbs, the dogs of this study bore an average of <31% on their pelvic limbs over the first 3 months post-operatively. The dogs of this study likely persistently leaned forward to compensate for ongoing pelvic limb weakness. This is consistent with a more cranial location of the center of pressure reported in dogs with SCI secondary to TL-IVDE (2, 3). Abnormal, compensatory shifts in static weight distribution have also been reported in dogs with pelvic limb osteoarthritis (6) and in experimentally-induced pelvic limb lameness in dogs (18). Forward shifting of body weight after TL-IVDE might be an expected finding among the dogs that remained non-ambulatory by study end. However, contrary to what we anticipated, even dogs that were strongly ambulatory still bore less weight on their pelvic limbs 3 months after injury and surgery as compared to normal controls. While we did not evaluate long-term outcomes, our findings support that altered weight distribution can persist in the short-term after TL-IVDE managed surgically.

Approximately 60% of the dogs in this study showed a >5% discrepancy in weight distributed between left and right pelvic limbs. While 85% of these bore more weight on the leg opposite

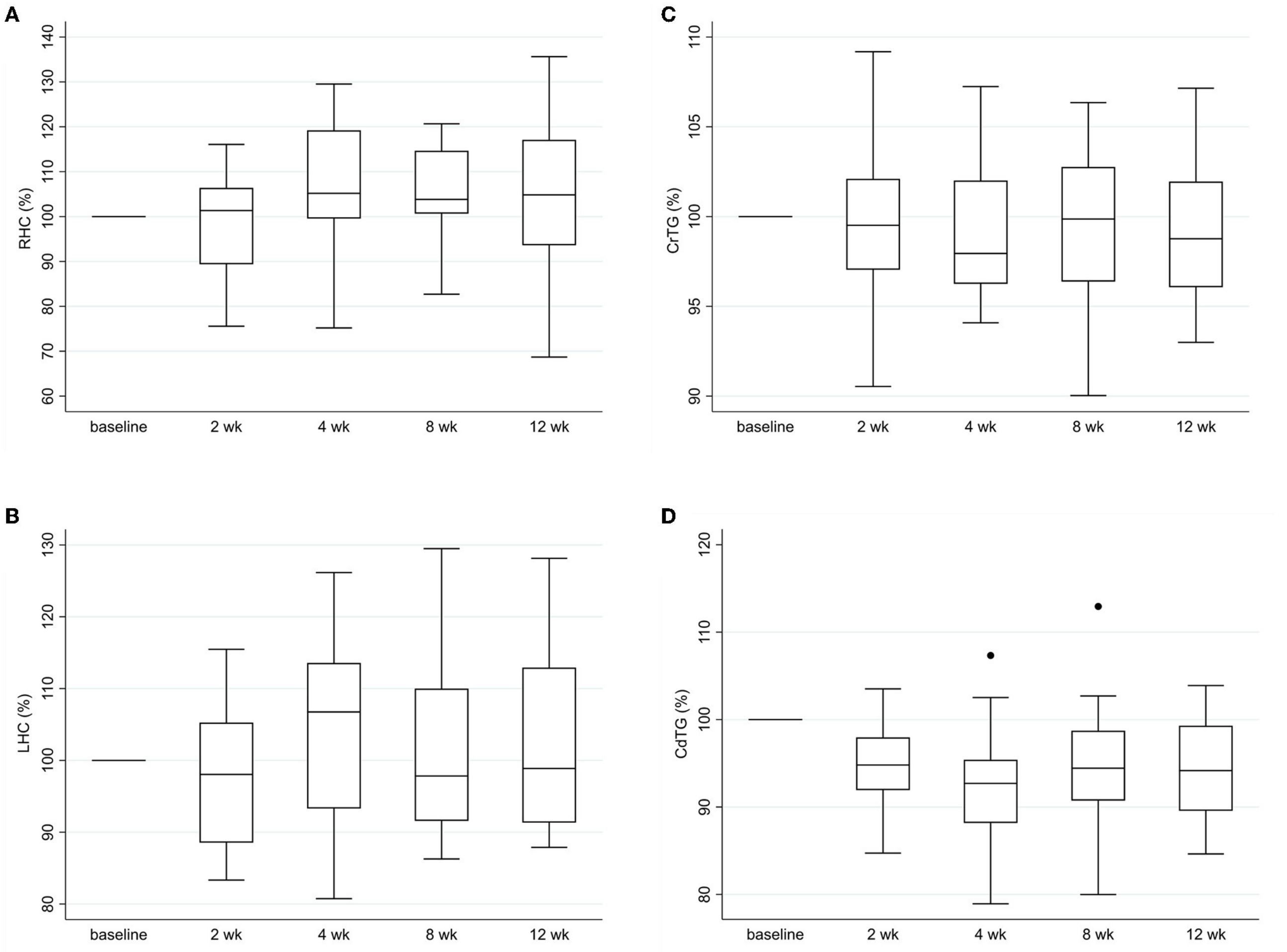

FIGURE 3 | Trunk and limb circumference measurements over time. **(A)** right thigh girth, **(B)** left thigh girth, **(C)** cranial trunk girth and **(D)** caudal trunk girth for each study visit as a percentage of baseline values. RHC: right hind limb circumference, LHC: left hind limb circumference, CrTG: cranial trunk girth, CdTG: caudal trunk girth.

the side of surgery, this relationship was not signfiicant, likely due to low numbers. Asymmetry of neurologic deficits between the pelvic limbs in dogs with TL-IVDE is common with the more severely affected limb typically corresponding to the side of greater compression and therefore the side of decompressive hemilaminectomy (19). This is also consistent with dogs with lameness secondary to stifle disease where dogs leaned away from the lame limb (18). However, of the 13 dogs designated as leaning, 7 leaned beyond the 5% cutoff at only a single visit. Three additional dogs leaned both left and right (on different visits) and four dogs did not lean notably in either direction at any visit. Additionally, asymmetry between pelvic limbs did not decrease over time as dogs recovered and was generally comparable to that of the healthy control dogs in which is was just under 5%. These findings highlight the limitations of measuring individual limbs, which was previously noted to be challenging in a study of weight distribution in large breed dogs with and without osteoarthritis (6). External factors such as handler position, leash side and location of a wall have been shown to impact dynamic weight distribution in walking dogs (20, 21), and could also impact SWD. We required dogs to stand still and squarely, but small shifts in position likely contributed to and magnified the variability of individual limb measurements, limiting the ability to utilize individual limb changes to track recovery.

While abnormal static weight distribution, notably leaning forward, persisted by 3 months post-operatively, the clinical relevance of these findings are unknown. A successful outcome for dogs with TL-IVDE has been defined as recovery of ambulation and continence and the resolution of pain (22, 23). While this is a functionally acceptable outcome, deficits in strength and coordination can persist (1–4). Binary assessment of ambulation (yes or no) or the commonly applied modified frankel score can have a ceiling effect in evaluating functional status once ambulation is achieved and are limited to detect more nuanced aspects of recovery (24). While the vast majority regained ambulation and 13/18 (72%) had normal or nearly normal OFS scores by study end, the altered weight distribution could perpetuate or exacerbate residual weakness in one or both pelvic limbs. In people with spinal cord injury, dynamic weight shifting exercises have been shown to enhance step length and walking distance and improve overall locomotor outcomes after injury (25, 26). Building upon our preliminary results, future prospective studies in dogs could more directly evaluate the effect of stance and weight distribution on recovery of locomotion following spinal cord injury. The role of rehabilitation exercises focusing on improving weight distribution when standing and ambulating is also a needed area of study.

Beyond ambulation, the implications for long-term decrease in weight bearing have not been studied in the context of TL-IVDE, but can be extrapolated from other contexts in which a variety of musculoskeletal changes have been described. There is evidence that immobilization alters nerve function and inter-joint coordination (27, 28). Canine models for ligament damage also showed that increased muscle loading results in greater range of motion and biomechanical properties of musculoskeletal tissues after experiencing injury (29). Additionally, chronically increased weight bearing on the thoracic limbs could contribute to or exacerbate osteoarthritis of the elbow or shoulder joints, or even perpetuate neurologic dysfunction or injury in the cervical or thoracic spine. In dogs with a left to right discrepancy, leaning away from a weaker pelvic limb could abnormally increase loading on the stronger limb.

Caudal trunk girth measurements decreased over time. By 2 weeks post-operatively, they were significantly lower than baseline and remained lower throughout the study period. While this change was small, it might reflect loss of muscle mass of the caudal lumbar epaxial and gluteal muscles in recovering dogs. This could be explained by overall reductions in body weight and generalized disuse atrophy secondary to post-operative activity restrictions, but forward shifting of body weight resulting in decreased hindquarter loading could have been a contributing factor. Mean thigh girth measurements decreased mildly at 2 weeks but were increased slightly at the final study visit compared to baseline values. While significant changes in thigh circumference were not identified across study visits, these findings are consistent with prior reports in dogs with TL-IVDE and stifle disease where small initial decreases in thigh circumference were noted (8, 13). In dogs with TL-IVDE, this decrease largely returned to baseline by 6 weeks post-operatively (13) and small increases in lean muscle mass have also been noted by 3 months post-operatively (14). Importantly, thigh circumference measurements presented several challenges. Limb conformation was previously noted to be a limitation for obtaining girth measurements in dachshunds (12). This study was not limited to dachshunds, but the vast majority were chondrodystrophic and limb conformation hampered performing consistent measurements, even for trained personnel. Additionally, some dogs were more relaxed than others when laying in lateral recumbency, and limb position (flexed or extended) was not standardized. In prior studies of circumference measurements in normal dogs and dogs with musculoskeletal diseases, thigh girth was noted to have poor reliability (11) and limb position affected results (8). In comparison, caudal trunk girth was performed with dogs standing squarely. This might have resulted in fewer variations in positioning and other patient-related factors, potentially leading to more reliable results between dogs and over time.

Physical rehabilitation is commonly recommended as a routine component of post-operative care for dogs with TL-IVDE (30). Despite the high frequency, there are few validated outcome measures available to evaluate the impact of rehabilitation protocols in neurologic dogs. Objective tools are commonly utilized in dogs with orthopedic injuries to determine success of post-injury physical rehabilitation (31). Our results demonstrate that measuring SWD using digital scales can be easily incorporated into post-operative assessment. With further standardization of acquisition protocols, circumference measurements, especially caudal trunk grith, might also be useful to track changes in muscle mass. Together, they could serve as objective targets for formal or informal rehabilitation programs, providing the rehabilitation practitioner with specific ways to broadly assess recovery from establishing a starting point to gauging success over time. Such measurements will allow improved design and adaptation of of individual therapy regimens for dogs with spinal cord injury. Future prospective clinical trials could investigate if exercises to emphasize pelvic limb weight bearing (e.g., walking up small inclines or utilizing ramps or balance boards) result in improved SWD and improved locomotor outcomes, and over what timeframe and intensity such exercises are needed to produce a quantifiable benefit.

Limitations of this study include a small sample size. While the majority of dogs completed all study visits, there was a small amount of missing data at each follow-up visit which further contributed to our limited numbers and could have influenced our results. We also only enrolled a small number of severely affected dogs. Paraplegic dogs with absent pain perception due to TL-IVDE have worse outcomes compared to dogs where pain perception is maintained (23, 32). This group might be most likely to benefit from physical rehabilitation; validation of outcome measures are warranted specifically to track their recovery. Across all dogs, evaluation over a longer time period might be needed to assess if some of the observed changes normalize with additional time and, even if persistent, if such changes are functionally or clinical relevant for a given dog. Additionally, validating these measurements with other objective markers such as bone density (DEXA) scans or assessment of muscle strength might be useful to evaluate their clinical utility.

Overall, dogs recovering from acute TL-IVDE demonstrated a persistent tendency to lean forward even among dogs with minimal to no visible gait deficits. These alterations in SWD might contribute to changes in muscle mass and perpetuate residual pelvic limb weakness.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Purdue Institutional Animal Care and Use Committee (protocol #1804001743). Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

NAM participated in data analysis, manuscript preparation, and editing and review. ST, JL, and MJL participated in study design, data acquisition and analysis, manuscript preparation, and editing and review. JB, ML, and KK participated in data acquisition and analysis, and manuscript editing and review. GEM participated in data analysis with statistical support, manuscript preparation, and editing and review. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.877402/full#supplementary-material

Supplementary Figure 1 | Two bathroom scales stance, side view (left) and top view (right).

Supplementary Figure 2 | Four kitchen scales stance, side view (left) and top view (right).

Supplementary Figure 3 | Body and limb circumference measurements. Top row: cranial trunk girth, cranial trunk girth close-up, thigh girth; Bottom row: caudal trunk girth, caudal trunk girth close-up.

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Internet Survey Evaluation of Demographic Risk Factors for Injury in Canine Agility Athletes

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Objective: The purpose of this study was to compare previously identified demographic risk factors for injury in agility dogs, and explore other potential associations with demographic risk factors in new populations, and across different levels of injury severity.

Procedures: An internet-based survey of agility handlers was conducted. The primary outcome was if the dog had ever had an injury that kept from agility for over a week. Demographic information about the dog and handler were recorded. Logistic regression was used to quantify associations between variables of interest with injury history and all models were adjusted for age. Analyses were stratified by geographic location. Final model building was done *via* backward selection.

Results: The sample included 2,962 dogs from North America and 1,235 dogs from elsewhere. In the North American sample, 8 variables were associated with injury history; dog breed, height and weight, handler age, gender, agility experience, competing at the national level, age dog was acquired, and taking radiographs to assess growth plate closure. In the non-North American sample, 4 variables were associated with injury history; breed, handler age, occupation (dog trainer or not), and handler medical training. In both samples, Border Collies showed a marked increase in injury risk (ORs 1.89 and 2.34) and handler age >65 was associated with lower risk (ORs 0.62 and 0.77). Consistent with previous studies, greater handler experience was associated with reduced risk in the North American sample, but the other sample did not show this pattern, even in unadjusted models. Dog spay/neuter status was not associated with injury risk in either sample.

Conclusions and Clinical Relevance: Dogs with radiographs assessing growth plate closure may have increased injury risk as this population of owners may plan to train their dog harder, and at an earlier age. This finding also poses the question of whether or not growth plate closure is a good indicator of safety for increasing training intensity. Knowledge of what risk factors exist for injury in agility dogs is imperative in determining direction for future prospective studies, as well as creating recommendations to help prevent injury in this population of dogs.

Keywords: agility, dog, canine, sports medicine, injury, demographics

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INTRODUCTION

Canine agility is a sport where a handler directs their dog through a course of pre-set obstacles, such as jumps, weave poles, tunnels, A-frames, teeters, etc., which need be completed within a specific time limit. Entries into events sponsored by the American Kennel Club have increased 38% (870,603 to 1,202,711) from 2009 and 2019, indicating a dramatic increase in the sport's popularity.[1] There has been an increase in reported injury rates in agility dogs, as demonstrated in a recent study from 2019 that reported an overall injury rate of 41.7%, a substantial increase from the 32% rate reported in 2009 (1, 2). The increase in popularity, competitiveness and injury rates indicates a need for updated and expanded information regarding risk factors for injury to these canine athletes.

Despite the increase in popularity and numerous changes that have occurred in canine agility in the past decade, there has been little updated information in regards to risk factors for injuries sustained by agility dogs. A previous study evaluating demographic risk factors for injury in agility dogs, published in 2013, by Cullen et al., reported that the Border Collie breed and <4 years of agility experience for dogs were associated with an increased risk of injury (1). The study also found that dogs having >4 years agility experience, and handlers with 5–10 years or >10 years handling experience were associated with a decreased risk of injury (1). A more recent study by Evanow et al. found that Border Collie breed, increased age, early spay/neuter and higher level of competition were associated with increased injury risk (3).

Both the Cullen et al. and Evanow et al. studies were done nearly exclusively in North American (United States and Canada) samples, raising the issue of whether or not risk factors for injuries might be different for dogs competing in agility in different geographic regions. Differences in injury type and injury frequency among agility dogs in different geographic regions have been previously reported (2), making it likely that there are also differences in risk factors between geographic regions. In greyhound racing, demographic risk factors for injury have been reported, and these demographic risk factors for injury have also been shown to vary by country and racing jurisdiction (4). Geographical comparisons of injury risks have not been evaluated in any other canine athlete population, including agility.

The purpose of this study was to investigate risk factors for injury in dogs competing in agility, focusing on handler and dog demographics, comparing previously identified risk factors and exploring potential associations with demographic factors in new populations and with different levels of injury severity. We hypothesized that less experienced handlers, competing at a higher level, and early spay/neuter would increase the risk of developing an injury. Based on differences observed in injury type and frequency by geographic region (2), we also hypothesized that demographic risk factors would vary by geographic region.

[1] Personal communication. Carrie DeYoung, Director of AKC Agility. Email. June 30, 2020.

MATERIALS AND METHODS

An internet-based survey (Qualtrics survey software, Provo UT) was conducted during a 6-week period in the fall of 2019. The details of this survey have been previously published (2). Briefly, participants who had at least one dog competing in agility in the past 3 years were eligible to fill out the survey. If participants had more than one dog that was eligible for inclusion, alphabetical order was used to select the dog for which the survey was completed (i.e., dog with name closest to letter "A"). Completion of the survey for multiple dogs was permitted, although this analysis was performed using only the first dog for each participant. The Ohio State University Institutional Review Board reviewed and approved the research protocol and survey.

Survey questions asked about demographic information for both the dog and the handler. Demographic information about the dog included age, height, weight, breed, sex/neuter status, country, age when acquired, from where the dog was acquired, if it was acquired with agility in mind, and if agility was the main sport focus. Handler demographics recorded included age, gender, education, profession (dog training professionally vs. not), medical training (veterinary, human, or none), and handler agility experience.

The primary outcome was history of any injury, defined as an injury that kept the dog from participating in agility for over a week, as reported by the owner. A secondary outcome, history of "severe injury" was defined as any injury where the dog was out of agility for more than 3 months.

Descriptive statistics (means and proportions) were first calculated for all variables. Separate logistic regression models were used to quantify associations between variables with the binary injury status outcome variables. All models were age adjusted to account for the differences in lifetime exposure for different aged dogs. For categorical variables, a multivariate Wald test was used to test for the overall association between that variable and injury history. In some cases, categories of responses were collapsed in order to avoid small cell sizes and facilitate interpretation; such adjustments were made prior to final model building and without respect to the association between the variable and the outcome of interest.

Risk factors were identified through backward stepwise selection in all models. The primary model used all available data and the outcome of any injury history for comparison with previous studies. To evaluate potential differences in risk factors between North American and non-North American agility dogs, models for risk of any injury were also constructed separately in the North American and non-North American subsamples. A final model evaluated risk factors for severe injury using all available data but with the outcome of severe injury (out of agility for longer than 3 months).

For all models, variables that were significant at $p < 0.20$ in models adjusted only for age of the dog were retained for variable selection. All variables retained from the initial selection process were included in the first adjusted model and then stepwise backward selection was used to eliminate the variable with the highest p-value until all variables in the model had $p < 0.05$. Data were analyzed using Stata 15.1 (College Station, TX).

RESULTS

The sample included data from 4,197 dogs, including 2,962 from North American and 1,235 from the rest of the world (**Table 1**). Injury keeping the dog from participating in agility for a week or longer was reported in 1,739 (41.4%) dogs total, with a higher rate reported in the non-North American sample (560 injured, 45.3%) compared to the North American sample (1,179 injured, 39.8%). Associations of all variables after adjusting for dog age are provided in **Supplementary Tables 1, 2**.

Among the entire sample, the final model for injury history included nine predictor variables in addition to dog age (**Table 2**). As previously reported, Border Collies were much more likely to report injury history than all other breeds, and as in previous studies, dogs of handlers with the most experience (>15 years) were the least likely to have an injury history, although the differences among other categories of agility experience were small.

Other variables associated with injury history have not been previously reported. Dogs whose handlers were over the age of 65 had the lowest odds of injury history, with the highest odds observed among handlers 25–34 and 35–44 years old. Dogs of handlers who reported having ever competed at the national level in agility had higher risk of injury, while dogs of handlers who are veterinarians or licensed veterinary technicians had lower odds of injury compared to other categories of occupation (**Table 2**). Dogs that were acquired at >12 months of age were less likely to report an injury history, even controlling for age and other variables in the final model, while there was little difference observed among different age categories below this threshold (**Table 2**). Dogs for whom agility was not the main sport focus were also less likely to have been injured, while dogs who had radiographs done to assess growth plate closure were at higher risk. Finally, owner-reported dog height and weight were jointly associated with injury history. Dog height was negatively associated with injury history, while dog weight was positively associated with injury history, indicating that among dogs of the same height, the odds of injury were greater for dogs who were heavier, controlling for breed and all other variables in the model.

In the North American sample, most of the same patterns were observed, with the final model including all the same variables except handler medical training and whether agility was the main sport focus of the dog (**Table 3**). In the North American sample, handler gender was included in the final model, with dogs of male handlers less likely to report injury.

In the non-North American sample, only four variables (in addition to dog age) were retained in the final model (**Table 4**). Border Collies were again more likely to have been injured, with an even higher odds ratio than in the North American sample, and, unlike in North America, Mixed Breed dogs were also at higher risk of injury relative to other non-Border Collie breeds (**Table 4**). Handler age was also again associated with injury risk, with dogs of older handlers (65+) at lower risk and dogs of handlers 25–44 at higher risk. Dogs of veterinarians and licensed veterinary technicians were at significantly decreased risk of injury history in this sample. Finally, unlike in the North American sample, dogs of handlers who reported that they were

TABLE 1 | Descriptive statistics of the sample (n = 4,197 dogs and handlers).

	Full sample (n = 4,197)	North American sample (n = 2,962)	Non-NA sample (n = 1,235)
Dog demographics			
Dog age (years)*	6.3 (2.9)	6.5 (3.0)	5.8 (2.7)
Dog height (inches)*	18.2 (4.3)	18.3 (4.4)	18.0 (4.1)
Dog weight (pounds)*	36.6 (17.6)	37.2 (18.4)	35.1 (15.6)
Breed			
Border Collie	934 (22.3)	565 (19.1)	369 (29.9)
Mixed breed	555 (13.2)	380 (12.8)	175 (14.2)
Shetland Sheepdog	277 (6.6)	203 (6.9)	74 (6.0)
Australian Shephard	285 (6.8)	244 (8.2)	41 (3.3)
Other	2,146 (51.1)	1,570 (53.0)	576 (46.6)
Country/Region			
United States	2,570 (61.2)	2,570 (86.8)	0 (0.0)
Canada	392 (9.3)	392 (13.2)	0 (0.0)
UK/Ireland	469 (11.2)	0 (0.0)	469 (38.0)
Cont. Europe	343 (8.2)	0 (0.0)	343 (27.8)
Australia	163 (3.9)	0 (0.0)	163 (13.2)
Other	260 (6.2)	0 (0.0)	260 (21.1)
Age brought dog home			
<8 weeks	868 (20.7)	602 (20.4)	266 (21.6)
8–12 weeks	2,246 (53.6)	1,545 (52.3)	701 (56.9)
13–15 weeks	230 (5.5)	164 (5.6)	66 (5.4)
4–6 months	241 (5.8)	171 (5.8)	70 (5.7)
7–12 months	238 (5.7)	186 (6.3)	52 (4.2)
>12 months	366 (8.7)	288 (9.7)	78 (6.3)
How acquired			
Breeder	3,092 (73.8)	2,170 (73.4)	922 (74.7)
Rescue/Shelter	708 (16.9)	527 (17.8)	181 (14.7)
Other	389 (9.3)	258 (8.7)	131 (10.6)
Acquired w/agility in mind			
No	1,214 (29.0)	787 (26.6)	427 (34.6)
Yes	2,978 (71.0)	2,171 (73.4)	807 (65.4)
Agility main sport focus			
Yes	3,016 (71.9)	2,075 (70.1)	941 (76.2)
Mostly	824 (19.6)	611 (20.6)	213 (17.3)
No	356 (8.5)	275 (9.3)	81 (6.6)
Sex/neuter status			
Male, intact	671 (16.9)	439 (15.7)	232 (19.5)
Female, intact	486 (12.2)	295 (10.6)	191 (16.1)
Male, neutered <10 months	377 (9.5)	285 (10.2)	92 (7.7)
Male, neutered 10–18 months	538 (13.5)	396 (14.2)	142 (12.0)
Male, neutered >24 months	421 (10.6)	312 (11.2)	109 (9.2)
Female, spayed <1 cycle	539 (13.6)	411 (14.7)	128 (10.8)
Female, spayed 1 cycle	367 (9.2)	235 (8.4)	132 (11.1)
Female, spayed >1 cycle	580 (14.6)	418 (15.0)	162 (13.6)
Front dew claws			
Intact	2,951 (70.4)	1,833 (62.0)	1,118 (90.6)
Removed	1,170 (27.9)	1,078 (36.5)	92 (7.5)
Unknown	70 (1.7)	46 (1.6)	24 (1.9)

(Continued)

TABLE 1 | Continued

	Full sample (*n* = 4,197)	North American sample (*n* = 2,962)	Non-NA sample (*n* = 1,235)
Rear dew claws			
Intact	782 (18.7)	378 (12.8)	404 (32.8)
Removed or born without	3,240 (77.4)	2,466 (83.4)	774 (62.9)
Unknown	165 (3.9)	112 (3.8)	53 (4.3)
Docked tail			
Yes	760 (18.1)	698 (23.6)	62 (5.0)
No/unknown	3,435 (81.9)	2,263 (76.4)	1,172 (95.0)
Growth plate x-rays			
Not done	3,432 (81.8)	2,336 (78.9)	1,096 (88.8)
Done at least once	763 (18.2)	625 (21.1)	138 (11.2)
Handler demographics			
Handler current age			
18–24	208 (5.0)	92 (3.1)	116 (9.5)
25–34	657 (15.7)	358 (12.1)	299 (24.4)
35–44	634 (15.2)	370 (12.5)	264 (21.6)
45–54	866 (20.8)	608 (20.6)	258 (21.1)
55–64	1,176 (28.2)	974 (33.0)	202 (16.5)
65+	633 (15.2)	548 (18.6)	85 (6.9)
Handler gender			
Female	3,915 (93.8)	2,782 (94.4)	1,133 (92.5)
Male	212 (5.1)	131 (4.4)	81 (6.6)
Other gender identity	46 (1.1)	35 (1.2)	11 (0.9)
Handler education			
Graduate or professional degree	1,389 (33.5)	995 (33.9)	394 (32.5)
4-year college	1,296 (31.2)	1,005 (34.2)	291 (24.0)
2-year college	452 (10.9)	352 (12.0)	100 (8.3)
Some college	586 (14.1)	408 (13.9)	178 (14.7)
HS degree (or less)	425 (10.3)	177 (6.0)	248 (20.5)
Handler profession			
Not a dog trainer	2,738 (66.1)	650 (22.2)	404 (33.1)
Paid trainer, not primary job	1,054 (25.4)	277 (9.5)	75 (6.2)
Professional trainer	352 (8.5)	1,997 (68.3)	741 (60.7)
Handler medical training/experience			
None of these	3,215 (77.9)	2,230 (76.4)	985 (81.4)
Veterinarian	149 (3.6)	105 (3.6)	44 (3.6)
Licensed vet tech	106 (2.6)	90 (3.1)	16 (1.3)
Veterinary assistant	96 (2.3)	66 (2.3)	30 (2.5)
Human health care professional	562 (13.6)	427 (14.6)	135 (11.2)
Handler agility experience			
<3 years	410 (9.8)	231 (7.8)	179 (14.5)
3–5 years	722 (17.2)	457 (15.5)	265 (21.5)
6–10 years	1,054 (25.2)	737 (24.9)	317 (25.7)
11–15 years	696 (16.6)	514 (17.4)	182 (14.8)
>15 years	1,308 (31.2)	1,018 (34.4)	290 (23.5)
Handler competed at national level			
No	1,893 (45.2)	1,349 (45.6)	544 (44.1)
Yes	2,299 (54.8)	1,610 (54.4)	689 (55.9)
Handler competed at international level			
No	3,744 (89.5)	2,761 (93.5)	983 (79.9)
Yes	439 (10.5)	191 (6.5)	248 (20.2)

Values are N (%) except for continuous variables (*) which are means (SD).

TABLE 2 | Coefficients from final adjusted model of risk factors of any injury using the full sample.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.17 (1.14, 1.20)	<0.001
Height & weight together		<0.001
Dog height (per 4 inches taller)	0.83 (0.73, 0.95)	
Dog weight (per 10 pounds heavier)	1.17 (1.08, 1.27)	
Breed		<0.001
Border collie	1.97 (1.64, 2.37)	
Mixed breed	1.03 (0.83, 1.28)	
Shetland sheepdog	1.18 (0.89, 1.56)	
Australian shephard	0.98 (0.75, 1.29)	
Other	Reference	
Age brought dog home		0.014
<8 weeks	0.99 (0.83, 1.17)	
8–12 weeks	Reference	
13–15 weeks	1.01 (0.75, 1.37)	
4–6 months	0.98 (0.73, 1.32)	
7–12 months	0.97 (0.72, 1.30)	
>12 months	0.62 (0.48, 0.80)	
Agility main sport focus		0.048
Yes	Reference	
Mostly	1.07 (0.90, 1.27)	
No	0.76 (0.59, 0.98)	
Growth plate x-rays		0.025
Not done	Reference	
Done at least once	1.22 (1.03, 1.46)	
Handler current age		<0.001
18–24	Reference	
25–34	1.30 (0.92, 1.86)	
35–44	1.27 (0.89, 1.82)	
45–54	1.08 (0.76, 1.53)	
55–64	0.92 (0.65, 1.30)	
65+	0.59 (0.41, 0.86)	
Handler medical training/experience		0.005
None of these	Reference	
Veterinarian	0.53 (0.36, 0.77)	
Licensed vet tech	0.68 (0.44, 1.05)	
Veterinary assistant	1.19 (0.77, 1.82)	
Human health care professional	0.90 (0.74, 1.09)	
Handler agility experience		0.035
<3 years	1.12 (0.84, 1.51)	
3–5 years	1.20 (0.96, 1.50)	
6–10 years	1.32 (1.09, 1.59)	
11–15 years	1.27 (1.04, 1.56)	
>15 years	Reference	
Handler competed at national level		0.007
No	Reference	
Yes	1.23 (1.06, 1.43)	

a professional dog trainer or that they were a trainer to others (if not their primary job) were at higher risk of injury in the non-North American sample.

TABLE 3 | Coefficients from final adjusted model of risk factors of any injury using the North American sample.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.17 (1.14, 1.20)	<0.001
Height & weight together		0.002
Dog height (per 4 inches taller)	0.84 (0.72, 0.99)	
Dog weight (per 10 pounds heavier)	1.17 (1.06, 1.29)	
Breed		<0.001
Border collie	1.89 (1.51, 2.37)	
Mixed breed	0.85 (0.66, 1.10)	
Shetland sheepdog	1.28 (0.93, 1.77)	
Australian shephard	0.95 (0.70, 1.28)	
Other	Reference	
Age brought dog home		0.001
<8 weeks	0.99 (0.81, 1.22)	
8–12 weeks	Reference	
13–15 weeks	1.20 (0.85, 1.70)	
4–6 months	1.01 (0.72, 1.43)	
7–12 months	1.14 (0.82, 1.59)	
>12 months	0.60 (0.45, 0.81)	
Growth plate x-rays		0.020
Not done	Reference	
Done at least once	1.26 (1.04, 1.53)	
Handler current age		<0.001
18–24	Reference	
25–34	1.17 (0.71, 1.94)	
35–44	1.25 (0.76, 2.07)	
45–54	1.13 (0.69, 1.83)	
55–64	0.93 (0.57, 1.49)	
65+	0.62 (0.38, 1.03)	
Handler gender		0.044
Female	Reference	
Male	0.64 (0.43, 0.94)	
Non-binary/differently identify	0.65 (0.31, 1.37)	
Handler agility experience		0.035
<3 years	1.12 (0.84, 1.51)	
3–5 years	1.20 (0.96, 1.50)	
6–10 years	1.32 (1.09, 1.59)	
11–15 years	1.27 (1.04, 1.56)	
>15 years	Reference	
Handler competed at national level		0.014
No	Reference	
Yes	1.25 (1.05, 1.49)	

Severe injury keeping the dog out for 4–6 months or longer (>3 months) was reported for 629 dogs, representing 15.0% of all dogs in the survey and 36.2% of the 1,739 dogs reporting any injury history. After model building, four variables (in addition to dog age) remained in the model with severe injury as the outcome: breed, history of radiographs to assess growth plate closure, handler age, and handler medical training (**Table 5**). As in the model for any injury, Border Collies were at significantly higher risk of severe injury compared to all other breeds. Dogs who had had radiographs done to assess growth plate closure were also at higher risk of severe injury. The oldest handlers (65+) were at lowest risk of reporting a severe injury to their dog and lower risk was also observed among handlers who were also veterinarians.

TABLE 4 | Coefficients from final adjusted model of risk factors of any injury using the non-North American sample.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog Age (per 1 year old)	1.20 (1.14, 1.25)	<0.001
Breed		<0.001
Border collie	2.34 (1.76, 3.11)	
Mixed breed	1.50 (1.04, 2.15)	
Shetland sheepdog	0.95 (0.56, 1.61)	
Australian shephard	1.26 (0.65, 2.46)	
Other	Reference	
Handler profession		0.003
Not a dog trainer	Reference	
Paid trainer, not primary job	1.54 (1.18, 2.00)	
Professional trainer	1.53 (0.91, 2.56)	
Handler current age		0.039
18–24	Reference	
25–34	1.52 (0.95, 2.43)	
35–44	1.40 (0.86, 2.26)	
45–54	0.99 (0.61, 1.60)	
55–64	1.05 (0.63, 1.73)	
65+	0.77 (0.41, 1.43)	
Handler medical training/experience		0.029
None of these	Reference	
Veterinarian	0.40 (0.21, 0.79)	
Licensed vet tech	0.38 (0.12, 1.19)	
Veterinary assistant	1.04 (0.49, 2.23)	
Human health care professional	0.77 (0.52, 1.13)	

DISCUSSION

Several variables associated with either increased or decreased odds of injury in agility dogs were identified in this study. Some risk factors that were identified in previous North American surveys were also consistent in our North American survey sample. However, patterns were not entirely consistent between geographic regions.

The most consistent finding is that the Border Collie breed had the highest odds of injury, in both North American and non-North American samples when considering only severe injuries. This result is consistent with previous studies (5, 6). Border Collies are known for their fast speed; speed has been associated with increased odds of injury in equine athletes and in racing greyhounds, though no studies have been performed to assess if this is true in canines overall or in a particular breed or sport (7–9). Additional studies focused on Border Collies and correlation between structure, speed and injury, as well as severity of injury, are needed for further assessment given the robustness of this association seen in our survey and the number of Border Collies competing in agility worldwide.

TABLE 5 | Coefficients from final adjusted model of risk factors of severe injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog Age (per 1 year old)	1.21 (1.17, 1.25)	<0.001
Breed		<0.001
Border collie	1.70 (1.37, 2.09)	
Mixed breed	0.84 (0.63, 1.13)	
Shetland sheepdog	0.98 (0.67, 1.44)	
Australian shephard	0.69 (0.46, 1.04)	
Other	Reference	
Growth plate x-rays		0.004
Not done	Reference	
Done at least once	1.38 (1.11, 1.73)	
Handler current age		0.003
18–24	Reference	
25–34	0.93 (0.59, 1.48)	
35–44	1.10 (0.69, 1.73)	
45–54	1.01 (0.65, 1.58)	
55–64	0.74 (0.47, 1.14)	
65+	0.56 (0.34, 0.90)	
Handler medical training/experience		0.012
None of these	Reference	
Veterinarian	0.69 (0.40, 1.17)	
Licensed vet tech	0.93 (0.53, 1.61)	
Veterinary assistant	2.10 (1.30, 3.42)	
Human health care professional	1.18 (0.92, 1.52)	

Handler age above 65 was associated with lower risk of injury in the overall sample, and both the North American and non-North American samples, although it has not been noted in previous studies. Additionally, handlers over the age of 65 had the lowest risk of reporting a severe injury. There was a somewhat elevated risk for middle aged (25–44) aged handlers relative to the youngest category (18–24). It is possible that younger handlers are choosing faster dogs, and training at a higher intensity in order to keep up with the increased competitiveness and faster course times that have arisen over the last decade. Further studies are needed to assess training and handling styles of different age groups and how that might be associated with injury development and severity of injury.

Handler medical experience was correlated with injury risk, though correlation varied between geographic regions. Dogs with handlers that had medical training, especially those that were veterinarians or veterinary technicians, had a decreased risk of injury, with the exception of veterinary assistants. This held true in the overall sample as well as the non-North American sample, but was not true for handlers with medical experience in the North American sample. Veterinarians in particular, were also at the lowest risk of reporting a severe injury to their dogs. Those with a more advanced veterinary background may be able to detect subtle lameness or changes to gait more easily, and take appropriate measures to prevent further injury, thereby also decreasing the risk of severe injury. They may also be more aware of injury risk in general and take additional proactive approaches to injury prevention. It is unknown why there was a difference in risk between the non-North American and North American samples.

The North American sample, in this study, showed the same previous association with handler experience where dogs of handlers with greater agility experience were found to have a decreased risk for injury (1). However, the non-North American sample did not show this pattern at all, even in unadjusted models. Handler experience was also not associated with risk of severe injury. Inherently, having more experience as a handler should facilitate better handling techniques and timing of cues, which may improve safety in course navigation and decrease injury rates. In the equine literature it has been demonstrated that increased jockey experience is associated with decreased horse falls during steeplechase and point-to-point racing (10, 11). Proposed causes for this finding in horse racing include increased jockey skill in navigating the horse through the courses and quality of jockey training (10, 11). More experience as a handler may also lead to quicker identification in subtle changes in the athlete, allowing them to adjust training or seek veterinary care prior to significant injury. However, it is unknown why this correlation between increased experience and decreased injury risk did not hold true in the non-North American sample, even though the distribution of handler experience was similar between geographic region samples. It is possible that selection bias was more pronounced in the non-North American sample, resulting in only the more serious competitors filling out the survey, regardless of experience level. It is also possible that there are other confounding variables that either make experience level in the North American sample look protective, or non-protective in the non-North American sample. Prospective studies are needed to further elucidate the correlation between handler agility experience and injury risk, as well as how experience influences training, handling and competition factors that could also be involved with injury development and risk.

Dogs of handlers who had a history of competing at a national level had an increased risk of injury. This risk factor was present in the overall sample and North American sample, but not in the non-North American sample. There was no association found between competing at a national level and severity of injury. It is likely that handlers with a history of competing at the national level are selecting dogs for agility specifically, which was also an identified injury risk factor. They may also be training more frequently, for more repetitions and pushing their dogs harder during training and competitions, which could potentially increase injury risk. Overuse and repetitive stress injuries are common among human athletes and often related to high training frequency, intensity, and repetitive movements (12–14). With a retrospective survey we were unable to evaluate many of the training subtleties that could influence injury development. Prospective studies looking at specific training practices of dogs competing at the national level are needed to evaluate risks of overuse and repetitive stress injuries, as are often seen in highly competitive human athletes (12–14). The difference between geographic regions could be due to the smaller sample size in the non-North American sample, or it is also possible that differences between geographic regions are due to varying terminology and definitions of national level competitions.

This study also found that, in the overall sample and North American sample, dogs acquired after 12 months of age were found to have decreased odds of injury. In the overall sample, those dogs for which agility was not the main focus also had a decreased risk of injury. Handlers and their dogs who are competing recreationally in agility likely do not train as hard, nor as often as those competing at a national level. It is also possible that, like in human athletics, early sport specialization increases the risk of injury, particularly risk of overuse injuries (15–17).

In the North American sample, for dogs of the same height, the odds of injury were higher for dogs that were heavier. This correlation was only identified in the North American sample and not in the non-North American sample. There was also no association with severity of injury. Unfortunately, given the nature of using a survey we were unable to accurately assess body condition score of dogs, and therefore cannot make conclusions regarding relation of body condition score and injury risk. Without accurate body condition scoring, it is impossible to determine whether the heavier dogs had an increased body condition score and were obese, or whether the increased weight was due to increased muscle mass. It is possible that those dogs that are heavier, in relation to their height, are less physically fit, and therefore are more likely to sustain an injury. This correlation has been described in human sports medicine (18), and may be true of canines as well. Increased weight, regardless of the fitness level, places increased stress on an athlete's joints, which could increase injury risk, even in fit animals, as is described in the human literature (19, 20). It is unknown why there was a difference between dog weight and injury risk in the North American and non-North American samples, however smaller sample size in the non-North American sample is likely a limitation. It is also possible that the variation between geographic regions could be due to different breed distribution. While these data were adjusted for breed, there may be differences in breeds making up the "mixed breed" and "other purebred" categories that could affect the results. Additional studies are needed to evaluate the effect of body condition score and physical fitness on injury development and risk in canine athletes.

An interesting finding in the overall and North American samples was a correlation between having had radiographs taken to confirm growth plate closure and increased odds of injury risk. These dogs were also more prone to a severe injury, keeping them out of competition or training for an extended period of time. The correlation between having radiographs taken to confirm growth plate closure and injury risk was not retained in the final model in the non-North American sample. Radiographs for assessment of growth plate closure were more commonly performed in the North American sample vs. the non-North American sample (22% of dogs vs. 11% of dogs, respectively). Therefore, it is possible that the correlation with injury risk is similar in both geographic regions, but that the smaller sample size in the non-North American sample limited the statistical significance.

It is thought that high impact training before growth plate closure may cause injury to the growth plates or contribute to developmental musculoskeletal disorders (21). In humans, it has been demonstrated that adolescent athletes are prone to physeal injury due to overuse, particularly during times of rapid growth (22). Recommendations for preventing physeal injury in human adolescents include limiting time spent on a particular sport, as well as 2–3 months without training or competition per calendar year (22). In the equine literature, a single paper from 1973, compared soundness between 2 year old racehorses with open vs. closed growth plates after a season of racing (23). The data suggested that racing with open growth plates did not result in an increase of unsoundness (23). However, no further growth plate-specific research has been performed in horses. In contrast to the human literature, research in racehorses has shown that horses racing or starting race training at older than 2 years had a higher risk of catastrophic musculoskeletal injury, possibly due to decreased ability to adapt to the dynamic strains placed on bone (24, 25). However, this may not be directly comparable to dogs, as the majority of catastrophic musculoskeletal injuries in horses are fractures (24). This is opposite of dogs competing in agility, where the most common injuries are soft tissue injuries (2).

There are anecdotal guidelines among agility trainers and competitors on general ages to start various training techniques, jump heights, and obstacle training. Growth plate closure is often used in the agility community to determine when to progress the intensity of training, increase the height of jumps, and start weave training, although there are no studies available to support the use of growth plate closure as a guideline in determining training progression. It is possible that the population of agility handlers that choose to have radiographs of their dogs made to assess growth plate closure do so in order to train harder, and at a younger age, which may be contributing to the increased injury risk. It is also possible that radiographic growth plate closure is not a good indicator of safety for increasing training intensity as it does not necessarily correlate with development and strength of the surrounding soft tissue structures, such as ligaments, tendons, and muscles, nor cartilage development (25, 26). Studies focusing on sports readiness in adolescents have found that most children are ready for participation in sports by the age of 12 (21). These studies not only consider physical aspects, but also include cognitive and psychosocial development as well, making it difficult to make any direct comparisons to our canine agility athletes. Within the equine literature, sport readiness is debated and the optimal level of exercise in young horses is unknown (25–27).

One can also consider that those handlers who had radiographs taken to assess growth plate closure may also represent a population that is more aware of potential injuries, and/or have more access to veterinary practitioners with sports medicine expertise, which may make them more likely to diagnose an injury. However, this would not explain why these dogs were also at a higher risk of severe injury, as one would think that earlier recognition would lead to a less severe injury and/or more rapid return to training and competition. Further studies specifically focusing on growth plate closure, canine sports readiness, effect of training intensity on musculoskeletal development and injuries are warranted.

One surprising finding was that, in the non-North American sample, dogs owned by handlers who were professional trainers had a significantly increased risk of injury. This association was not observed in the North American sample. It could be hypothesized that handlers who are professional trainers are more likely to push their dogs harder in both training and competition in order to achieve success at high levels of competition, as this could affect their reputation and client demand. However, if this hypothesis were generally true, it would be expected that the association with increased injury risk would be found in the overall sample, as well as the different geographic samples, which was not the case. It is unknown why dogs of North American professional trainers did not have an increased injury risk, but those of non-North American trainers did. It is likely that there are training and competition differences between the North American and non-North American professional trainers that could result in injury risk differences. Prospective studies are needed to evaluate differences in training and competing among professional agility trainers between different geographic regions, and how that may influence development of injury.

Counter to our hypothesis, early (<12 months of age) spay/neuter was not associated with injury risk in the North American, non-North American or combined samples. Early spay and neuter practices have been associated with increased risk of joint disorders in certain breeds (28). One previous study on agility demographics did demonstrate a correlation between early spay/neuter and increased risk of injury in agility dogs, though there were very small cell sizes for some groups (3). In the current survey, however, no association was found between spay/neuter status and injury risk, in any geographic region, despite larger sample sizes. Additional studies are needed for further evaluation of association between spay/neuter status and injury risk in the sport dog population specifically.

In a study by Sellon et al. removal of dewclaws was associated with increased risk of digit injury (29). As such, we hypothesized that dewclaw removal would be associated with increased injury risk in our study population. Conversely, in this survey, presence or absence of dewclaws was not found to be associated with injury risk. However, these data evaluated variables in relation to overall injury risk, as opposed to individual anatomic locations or types of injury. It is possible that dewclaw removal is associated with increased risk of injury of specific anatomic locations or types of injury, but not overall injury risk.

Kinematic studies in dogs have demonstrated the importance of tail movement in maintaining balance during treadmill locomotion (30). This may be even more pronounced during advanced movements, such as performance of agility obstacles. We hypothesized that the resultant biomechanical changes from the absence of a tail may increase forces on the dog's body, resulting in increased injury. However, in this survey, presence or absence of tail was not found to be associated with injury risk. Biomechanical studies are needed to evaluate differences in movement patterns in relation to presence/absence tails, and how these movement patterns are associated with injury development and risk.

Limitations of this study include potential recall bias due to retrospectively collected data *via* survey. These data were also reported by handlers and were unable to be verified by a veterinarian, which could result in inaccuracies in injury data. Selection bias may also be present, so our findings may not be representative of the entire agility dog population. Data on severity of injury was based on time off from agility, which may not be an accurate depiction of the true severity of an injury due to other extenuating variables. Many of the observed associations in the North American sample that did not persist in the non-North American sample are likely sample size issues (given that there were similar trends seen outside of North America in the unadjusted models, but the other countries had smaller sample size).

Overall, this study confirmed previously reported increased risk for injury for Border Collies, and decreased risk for injury with greater handler experience. This study also identified new variables affecting risk for injury such as dog weight in relation to height, age at which the dog was acquired, agility as main sport focus, radiographic assessment for growth plate closure, handler medical training, handler occupation, and handler history of competition at a national level. Furthermore, this study identified differences in demographic risk factors between the North American population of handlers and the non-North American population of handlers. The results of the current study provide insight on risk factors for injury, as well as a basis to guide further research. More research is needed to evaluate the increased injury risk in Border Collies, how weight and body condition affect injury risk in canine athletes, how canine musculoskeletal development is impacted by training, and how handling factors impact injury risk. Knowledge of what risk factors exist for injury in agility dogs will aid in creating recommendations for training and veterinary care in order to help decrease injury in this population of dogs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the Ohio State University Office of Responsible Research Practices determined the project was exempt from IRB review because it was an owner-based internet survey and the information was recorded without direct or indirect identifiers. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ASu participated in data evaluation and writing the manuscript. AP and NK assisted in study design, data collection, data evaluation, and writing the manuscript. ASh participated in study design, statistical analysis, and writing the manuscript. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.869702/full#supplementary-material

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REVIEW
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Proposed Canadian Consensus Guidelines on Osteoarthritis Treatment Based on OA-COAST Stages 1–4

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The Canadian consensus guidelines on OA treatment were created from a diverse group of experts, with a strong clinical and/or academic background in treating OA in dogs. The document is a summary of the treatment recommendations made by the group, with treatments being divided into either a core or secondary recommendation. Each treatment or modality is then summarized in the context of available research based support and clinical experience, as the treatment of OA continues to be a multimodal and commonly a multidisciplinary as well as individualized approach. The guidelines aim to help clinicians by providing clear and clinically relevant information about treatment options based on COAST defined OA stages 1–4.

Keywords: osteoarthritis, physical rehabilitation, weight management, non-steroidal anti-inflammatories, nutraceuticals, canine, treatment guidelines

INTRODUCTION

Osteoarthritis (OA) is a challenging disease for veterinarians, patients, and pet owners. The chronicity and disease complexity require extensive education of the pet owner and a willingness to begin a treatment plan for their pet requiring multiple re-assessments over a pet's life dependent on disease progression. The situation is further challenged for veterinarians, as there are a multitude of potential OA treatments, but there is no clear differentiation or priority based on OA stage. It is these understood challenges that led to the specific aim behind the guideline development, to provide prioritized treatment guidance based on clinical experience, with consideration of the available scientific evidence, enabling the Canadian veterinary practitioner to treat and discuss OA based on the different OA stages.

The guidelines are the result of a consensus among a group of Canadian experts in the field of OA including board certified surgeons, anesthesiologists, sports medicine and rehabilitation practitioners, pharmacologist, and general practitioner. The panel members were asked by the lead author to participate in this project based on their clinical expertise, academic knowledge, and active participation in OA education in Canada. A focus for the selection of Canadian members was placed on diversity of fields of interest within OA treatment to represent the clinical, academic and collaborate approach. In the spring of 2021, the panel members virtually met with the goal of creating Canadian specific, OA treatment guidelines based on OA stage. To help frame the initial conversations of the panel, 5 different sample cases were provided ahead of the meeting, with each case representing a typical clinical presentation for the different COAST stage of OA. Each panel member reviewed the cases independently and submitted their approach prior to the meeting. During the meeting, the cases were used to focus the conversation on where treatment approaches were similar or different among the members, discuss specific aspects of the treatment and evaluate the treatment based on scientific support and clinical experience. In addition, topics or challenges that are encountered when treating patients with OA were discussed, i.e., how the panelists approach lowest effective dose, challenges in pain assessment.

After the case discussions finished, the panel moved on to discuss more generally, how to adjust the treatment approach based on the different COAST stage. Each treatment was then evaluated and voted on. In order for a treatment to be classified as "core" it required 9/9 agreement. Therefore, core treatment recommendations were unanimously agreed on to be included in any case with OA with specific nuances adjusted to the different stages and individual patient. If a treatment did not receive unanimous support, it was classified as secondary, and then further discussions occurred as to at what stage, and when the treatment should be considered. The secondary treatments received varying levels of support due to the often lack of available research for a particular treatment, and instead those in favor of the treatment, provided their clinical knowledge and experience. A consensus was reached for when to start the secondary treatment options based on the COAST stage, however, there was no priority assigned (which order to start treatment A, then B, etc.) and instead the treatments were simply grouped. Overall, the authors focused on available or soon to be available treatment options in Canada.

In human medicine, chronic pain guidelines are based on evidenced based medicine and therefore backed up by extensive scientific studies, that provide appropriate evidence. In veterinary medicine such work with clear evidence is unfortunately not available in chronic pain management. The limitations are mainly due to inadequate objective pain assessments, and knowledge gaps remain within most treatment options, despite many efforts from well-performed studies.

This review article summarizes the consensual guideline results, that were based on the shared opinions of the Canadian experts using evidence-considered treatment information and their own clinical experience. Compared to the classical evidence based approach adopted in human clinical guidelines, the scope of this review is therefore more narrow in focus, documenting the scientific, and clinical insights of the panel members. Within the description of each treatment option, a focus was placed on explaining the mechanism of actions and pharmacology of each treatment to increase the reader's knowledge and understanding of its benefits or limitations as a potentially effective treatment in canine OA. The literature citing reflected this focus.

OSTEOARTHRITIS

Osteoarthritis is the most common joint disease affecting dogs. Most papers reference that ∼1 in 4 dogs are affected (1–3), although it has been suspected that this number may be an underestimation due to this disease being underreported until later stages (3). It has to be mentioned that the actual original studies that continue to be referenced are either older, have a small sample size, or represent a very specific regional selection, among other limitations, and show a variety of OA prevalence results (4–6). Osteoarthritis is a disease of the entire joint organ with loss and dysfunction of the articular cartilage and is usually highly inflammatory in nature. Resulting changes will progressively impact all structures within the joint, including a thickened joint capsule with inflamed synovium and reduced viscosity of synovial fluid, damage to cartilage and subchondral bones, and development of osteophytes. The etiology of OA is complex with local mechanical as well as systemic and metabolic contributing factors (7–9). The chronic and progressive characteristics make it a challenging disease for clinicians to control. In addition, the treatment recommendations in the literature can be inconsistent and vague, and the clinical approach often varies among veterinarians. The individual case response, including both patient and client variability, adds to the complexity when making decisions for a treatment plan. The age of the dog and the different stages of the disease further impact treatment decisions and create more confusion due to inconsistencies in recommendations. When left untreated, OA can progress to a severe debilitating disease with significant functional impairment and pain sensitization. Early detection of OA and early treatments are considered important

Abbreviations: ALA, alpha lipoic acid; APC, autologous platelets concentrate; APS, autologous protein solution; ASU, avocado soybean unsaponifiables; bFGF, basic fibroplastic growth factor; CB1+2, cannabinoid receptor 1 and 2; CBD, cannabidiol; CBDa, acid form of cannabidiol; COAST, canine osteoarthritis staging tool; COX, cyclooxygenase enzyme; CTX-II, c-terminal cross-linked telopeptide of type-II collagen; DHA, docosahexaenoic acid; DMOAD, disease-modifying osteoarthritis drug; DPA, docosapentaenoic acid; ECS, endocannabinoid system; EGF, epidermal grow factor; EPA, eicosapentaenoic acid; EP4, E-type prostanoid receptor 4; ESM, eggshell membrane; ESWT, Extracorporeal Shock Wave Therapy; FA, fatty acids; FAAH, Fatty acid amide hydrolase; HA, hyaluronic acid; IL-1 or 8, interleukin-1 or 8; Laser, **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation; LLLT, Low Level Laser therapy; LOAD, Liverpool osteoarthritis in dogs questionnaire; mAb, monoclonal antibody; MMP-13, matrix metalloproteinase 13; MSC, mesenchymal stem cells; NGF, nerve growth factor; NMDA, N-methyl-D-aspartate receptor; NO, nitric oxide; NPN, natural product number; NSAID, non-steroidal anti-inflammatory drug; NTR, neurotropin receptor; OA, osteoarthritis; PD, pharmacodynamics; PDGF, platelet-derived growth factor; PEMF, pulsed-electromagnetic field therapy; PG, prostaglandin; PK, pharmacokinetic; PPA, pentosan polysulfate sodium; PRP, platelet rich plasma; QoL, quality of life; ROM, range of motion; T1/2, half life; TGF-ß1 and 2, transforming growth factor beta; THC, tetrahydrocannabinol; THCa, acid form of tetrahydrocannabinol; TNFα, tumor necrosis factor alpha; TrkA, tropomyosin-related kinase receptor; TRPV, transient receptor potential cation channel—vanilloid; UC-II, type II Collagen; VEGF, vascular endothelial growth factor; VGCC, voltage gated calcium channel.

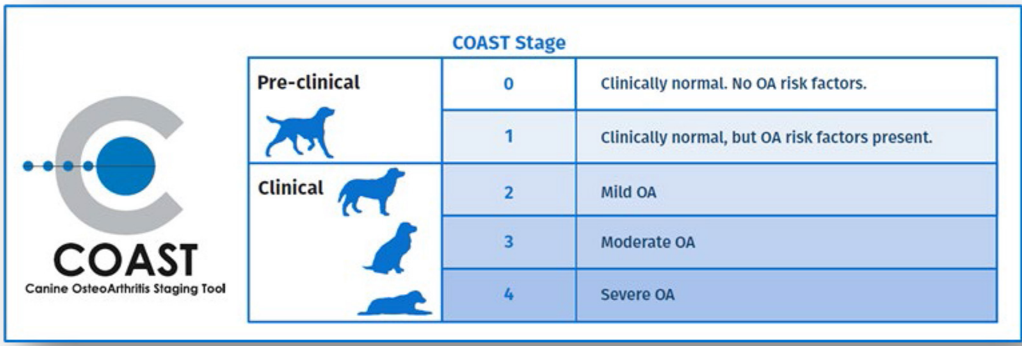

FIGURE 1 | OA stages based on Canine OsteoArthritis Staging Tool (COAST). Image courtesy of Elanco.

aspects in slowing down the progression of the disease and enhancing the quality of life (QoL) of the pet.

Regarding identifying the patient's stage of OA, the Canine OsteoArthritis Staging Tool (COAST) is a helpful diagnostic tool to assist veterinarians -with input from pet owners-, in recognizing and treating canine OA from its earliest stages (10). The tool provides clear guidance on how to decide on a dog's current OA stage based on owner input, orthopedic exam, and radiographic findings. The COAST stages include 0 (clinically normal, no risk factors), 1 (clinically normal, but OA risk factors present), 2 (mild OA), 3 (moderate OA), 4 (severe OA) (**Figure 1**). The descriptions of each stage are included in the category discussions below.

With OA, it is important to identify risk factors early in the disease and intervene before significant clinical signs occur, with the goal of preventing and/or slowing the progression (11). For consistency and to ensure clear definitions of each stage, these treatment guidelines are based on the COAST definitions of OA stages 1–4. We have not included Stage 0 as a stage that requires treatments but recognize that due to the high prevalence of OA in dogs, it is important for veterinarians to provide OA risk factor and prevention education at an early age even in this stage. The general education and Stage 1 discussion points also apply to Stage 0.

TREATMENT GUIDELINES

General Treatments Regardless of Stages

For all stages of OA, **client education** is fundamental. The veterinarian's role to educate owners on the disease (including pathology, risk factors, progression, stages, and identification and recognition of pain behaviors) is crucial. Education also includes relevant components like nutrition, specific diets, weight management, regular assessments, and therapeutic options (pharmaceutical, nutraceutical, physical medicine modalities, importance of exercise, lifestyle changes, and home improvements).

Osteoarthritis is a painful disease that results in limitations to the dog's ability and can progress to being severely debilitating. Education and empowering owners to recognize and identify the early signs of pain will help with early detection and treatment of the disease. Signs of pain in the later stages can help evaluate treatment response as well as its impact on the QoL of the pet. Signs in the early stages (Stages 1 and 2) can be subtle like asymmetric posture when standing or sitting, slight difficulties in rising or laying down, reluctance to jump into car, reluctance to play, young dogs not able to keep up with others, and difficulties with stairs. Pain in the later stages of OA is described below in their specific stage (Stage 3 and 4).

For general treatment recommendations, one common denominator in all OA stages is **weight management** (reaching and maintaining an ideal body condition score) (12–15). Obesity has been considered a high-risk factor for the development and progression of OA. Historically, this was ascribed to the excessive biomechanical joint loading on the articular cartilage, because of increased body weight, causing micro injuries and subsequent wear and faster breakdown. However, the association between obesity and OA in non-weight-bearing joints suggests a more complex etiology for obesity-induced OA. A more important part of the pathogenesis of OA could be the systemic and metabolic effects of obesity (inflamed adipose, dyslipidemia) (16, 17). Fat produces systemic inflammatory factors (cytokines and adipokines), which are specific adipose tissue-produced factors with significant inflammatory properties (18), which we presume from other species' extrapolation is also the case in dogs. The influence of adipose tissue attributing to low-grade systemic inflammation has been recognized and a weight loss program has shown both in humans and dogs to have general health benefits and potentially decrease and slow down the progression of OA in humans (19) and dogs (15), and is therefore considered by many an actual treatment option (20). Thus, an increase in body weight has been demonstrated to have negative effects on the osteoarthritic joint load (21) and maintaining optimal body condition should be one of the most important goals for any patient at any OA stage in the opinion of the panel. A specific effort should be made to educate and support owners in a weight reduction plan for their pet. This includes nutrition counseling for the right diet (weight or joint health focused or both), including both caloric and omega 3 fatty acid (FA) dose recommendations. This can also be used for a weight maintenance plan throughout the patient's life.

Dogs with OA require **regular exercise**. This is an important aspect of OA management for dogs. Exercise may be modified depending on the disease stage, but it is crucial that dogs with OA maintain a regular exercise plan that limits high impact and torsion to minimize joint trauma to help keep the joints mobile, cartilage healthy, and maintain muscle strength to support the joint (22–25). Historically "prolonged rest" was prescribed in cases with OA pain. This approach has the disadvantage that when a joint lacks movement, it will stiffen further (fibrosis) and decline cartilage health (26). A lack of exercise will contribute to muscle atrophy, thereby further reducing joint stability and contributing to pain (27, 28). The practice of severe activity restriction or rest is generally not recommended, instead regular, low impact exercise is an important part of pain management in OA. Regular physical activity is crucial to slow down the progression of sarcopenia and maintain physical fitness in dogs with OA (29), including the geriatric population. The specific type and frequency of exercise is dependent on the different stage of disease as well as the joints affected. Examples of low impact exercises could be frequent daily leash walks and a program with specific or targeted therapeutic exercises.

Specific Recommendations for the Different Stages

Recommendations for specific stages of the disease will be presented below and are useful starting points for most animals at each stage.

Serial monitoring of these patients is necessary, and treatment should be adapted according to the patient's response. Please note that multiple joints can be affected, and each joint may be in a different OA stage. There was agreement among the expert panel that targeting the joint with the worst OA stage will ensure an appropriate treatment plan for the patient. This was in agreement with the COAST reference of OA staging (10).

Please note, when reviewing the treatment guidelines, the below considerations may require adjustment of the therapeutic approach:

- Multiple joints affected requiring specific targeted therapies for an individual joint.
- Additional co-morbidities or concurrent medications present.
- Adverse events encountered in response to therapy.
- Surgical therapies were beyond the scope of the guidelines, please consider surgical interventions as appropriate for the patient.

Some of the suggested treatments are not licensed for the use in dogs or may have limited scientific evidence specifically for OA in dogs. It is the veterinarian's duty to make a risk:benefit assessment for each patient prior to administering any treatment and provide all relevant information related to the treatment.

Coast Stage 1

Stage 1 refers to a patient that is currently normal (preclinical) but has risk factors for developing OA (10). Based on the COAST literature, our panel identified that risk factors may include a genetic predisposition, extensive, and longterm participation in injury prone activity, a joint injury or surgery, and excess body weight or age. A typical COAST Stage I dog would be a specific breed with atypical limb conformation either breed related (i.e., Basset Hound, Bulldog, German Shephard etc.) or congenital/traumatic deformities (elbow/hip dysplasia; giant breed dogs) that could cause abnormal joint loading. The treatment is focused on the prevention of the disease.

Treatment Goals

Provide adequate education to owners about the high prevalence and risks of canine OA as well as early recognition and clear prevention measures. Maintaining joint health is a priority in this stage. If a joint injury or surgery are contributing factors, the importance of effectively controlling inflammation and pain in the peri-and post surgical/injury time is imperative.

Prioritized Treatment

For Stage 1, client education begins with a strategy for growing puppies, including nutrition, weight management and exercise, as stated above. More specific education for this stage include education on the risk factors, as well as guidance for specific training and exercises for injury prevention. Owners of working and sporting dogs may especially need a reminder about the importance of regular musculoskeletal assessments for early recognition of OA.

Diet and Omega 3 Fatty Acids

In dogs with a higher risk factor for OA, a diet with focus on joint health is ideal to ensure that the dietary ingredients included support the musculoskeletal system. In particular, omega 3 FAs have shown to be effective in reducing the signs and progression of OA (30–38), although it is important to provide adequate dosing (39). Most joint health focused diets have omega 3 FAs at varying dosing ranging from 0.59 to 10.11 g/1,000 kcal, with many brands being under 3.5 g/1,000 kcal (40). It is imperative to identify the actual eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) concentrations in the food, as not uncommonly alpha lipoic acid (ALA) is used in foods for its omega 3 FA content. As described below ALA is not an adequate substitute and food should quantify actual levels of DHA and EPA. In most cases, additional DHA/EPA supplementation is required to reach the scientifically recommended minimum dose of 100 mg/kg daily DHA/EPA (32). The type of omega 3 FA supplementation for adequate conversion to DHA/EPA should be based on current scientific evidence. The precursor of DHA/EPA in plants is ALA. The conversion rate from plant-based ALA to EPA is significantly less than from fish/marine based oil and a full conversion from ALA to DHA does not occur, only to its precursor docosapentaenoic acid (DPA) (41, 42).

TABLE 1 | Summarized core treatment recommendations for COAST Stage 1.

STAGE 1	
Core treatment recommendations	
Client education	Risk factors identification, disease prevention, assessment plan
Weight optimization and nutrition	Adequate DHA/EPA supplementation, joint focused diets
Regular exercise	Well-balanced training and injury prevention
Physical rehabilitation	Injury prevention strategies, risk factor identification, muscle strength support

Higher conversion rates with significantly more reduction of inflammatory markers were found with fish/marine based oils. In some patients, the joint health focused diet may need to be assessed for calories to reflect weight management goals and activity levels. Weight optimization is recommended throughout the patient's life as mentioned above.

Rehabilitation

Depending on the risk factors for the dog, a rehabilitation veterinarian can be sought out to discuss disease prevention, strategies to slow down progression of disease, and recommend therapeutic exercises to promote strengthening of muscles supporting joints. For an athletic or service dog, adequate training tips for injury prevention may be beneficial (*i.e.*, focusing on strength, endurance, proprioception, limiting repetitive, and concussive activity). For a dog with a genetic or breed specific predisposition, specific exercises could be useful to implement into daily activities (43).

These consults by a veterinarian or rehabilitation practitioner may also include lifestyle and household modifications, for example, daily exercises (including walks, swims) or household modifications (early teaching of a young Dachshund not to jump on and off a sofa, adding in a step stool, improving flooring traction, etc.).

A summary of stage 1 treatment recommendations is provided in **Table 1**.

Coast Stage 2 (Mild OA)

Stage 2 refers to the early clinical stage of osteoarthritis that results in mild clinical signs. Those signs can be inconsistent and subtle, can occur with some activities or after activities, may affect the gait and show subtle changes/shifting in body weight distribution and limb loading. Range of motion (ROM) of a certain limb/joint may be minimally reduced, but crepitus is unlikely at this stage. Minimal osteophytes and early signs of OA may be visible on diagnostic imaging (10).

Treatment Goals

The treatment goals at this stage are supporting the preservation of healthy cartilage and treating flare ups promptly and effectively. Providing owner education on recognizing signs of OA and importance of early as well as longterm treatment can be teadious, but is needed for the desired compliance.

Prioritized Treatment

Client education encompasses all points mentioned in the general treatment recommendation section as well as the Stage 1 specific education points.

A joint health focused diet and weight optimization are recommended as mentioned in the general section. DHA/EPA at a minimum of 100 mg/kg daily dose should be included within the diet or additionally supplemented.

Further important Stage 2 discussion topics include the progression of OA from mild to moderate stages, the importance of regular orthopedic assessments and monitoring response to therapy, as well as developing an exercise program suited for the patient. Daily exercise is necessary and should be low to moderate impact, for example walks, swims or specific physical exercises as recommended (43, 44). Exercises with high impact or torsion, like ball throwing, should be avoided. A specific fitness and exercise plan is necessary to be set in place for working dogs that require to return to work. This plan would be based on the type of work, the type of joint/dog concerns, and should focus on further injury prevention.

A consultation with a rehabilitation practitioner (when possible) would be beneficial to identify factors that may contribute to the faster progression of the disease and help with tips on how to decrease risk factors and optimize muscle strength, posture, proprioception, and gait. An initial assessment of gait, weight bearing, transitions, posture, body condition score, muscle condition score, ROM, and pain scoring provides a baseline evaluation of musculoskeletal health. Understanding what areas need improvement allows for a more individualized treatment plan. Targeted therapeutic exercises may focus on core strength and posture, maintaining or gaining ROM, improving overall physical fitness, and strengthening the musculature that is required to provide stability for arthritic joints (28, 45). Specific exercises should be prescribed depending on location of arthritis, concurrent illness, pain level, temperament/trainability of the dog, physical limitations of the owner, physical strength and endurance of the dog, home environment (i.e., condo vs. farm dog) and it is beyond the scope of this paper to address the multitude of situations. In addition, there are many options including manual therapy, physical medicine modalities, and rehabilitation equipment that can be utilized to treat and manage the arthritic patient. A rehabilitation program at this stage may include a combination of both specific home exercises and a formal in-clinic rehabilitation program.

As part of the client education or the rehabilitation consult, lifestyle and household modifications should be included at this stage. These may incorporate modifications in the house (stairs, flooring) or car (adjusted jumping out or in) to prevent high impact injuries and start learning/switching habits for future mobility concerns.

For **pain management**, the use of **non-steroidal anti-inflammatory drugs (NSAIDs)** is warranted for this stage, as a patient is demonstrating clinical signs. Due to the inflammatory nature of OA especially at the early stage (46, 47), NSAIDs play a significant role in decreasing the pathogenesis of peripheral sensitization. Prostaglandins (PG), in particular PGE_2, are one of the main inflammatory mediators in arthritis and will contribute to the transition from acute to a maladaptive chronic pain state when untreated (48, 49). Therefore, NSAIDs are considered to be the cornerstone of rheumatoid arthritis and OA treatment, providing effective pain relief, especially in this initial clinical stage by inhibiting cyclooxygenase (COX) activity and subsequently blocking the production of prostanoids, including PGE_2 (50, 51). When the production of this prostaglandin is increased in response to an inflammatory event, PGE_2 is more readily available to bind to its specific receptor [E-type prostanoid receptor 4 (EP4 receptor)] on the presynaptic side at the site of inflammation, resulting in a pain signal to be sent across the synapse and subsequently travel up the pain pathway. Without interference and continuing phasic and/or static nociceptive input, the constant stimulation from PGE_2 *via* the EP4 receptor pathway will lead over time to an increase in the sensitization of sensory neurons. The EP4 receptor will be upregulated in a prolonged state of inflammation (52). Upregulation means that the receptors are in a higher state of alert and increase in number. This constant activation results in further pain and increased inflammation. The ability to dampen the receptors (piprant class NSAID) or decrease available inflammatory prostaglandins (COX-2 selective inhibitory NSAIDs) will decrease the pain sensitivity and contribute to limiting sensitization (49), that could lead to chronic maladaptive pain.

The response to NSAIDs can be individual and the right fit regarding efficacy, adverse events, and predicted duration of use should determine the choice of a specific NSAID for the patient. Considering the importance of NSAIDs in the disease of OA, sometimes a patient may need to switch to a more suitable NSAID after the appropriate washout period (53, 54).

For dogs, this panel all agreed on a NSAID trial for a minimum of 4 weeks at product's labeled dose. The minimum of 4 weeks is recommended to allow for an adequate decrease of inflammation (55). Improvements of clinical signs may show earlier than 4 weeks, but the consensus is to treat for the full duration of the NSAID trail to resolve the inflammation on a cellular level. As most adverse events commonly occur in the early phase of initial treatment, a "check-in" call after 1 week to discuss the patient's tolerance and acceptance of the medication is recommended. After the 4-week trial, the patient should be reassessed clinically and, based on therapeutic response, the treatment can be continued or discontinued as appropriate. Not uncommonly it is recommended to continue NSAID therapy long-term to allow for effectively treating the underlying inflammatory nature of OA at this stage. With long-term NSAID use, bloodwork is recommended with a baseline CBC/Chemistry prior to initiating NSAID treatment and then every 3–6 months as needed, unless concerns about the health of the dog arise earlier.

"Flare-ups" (also known as "acute-on-chronic-episodes") can occur because of activity, injury, weather, and should aim to be minimized (56). In the occurrence of a flare up with clinical signs, if NSAIDs are not currently being used in the patient, a trial should be most strongly considered to keep the inflammation at a minimum as currently the only product proven to be effective to achieve this are NSAIDs. Median duration of flare-ups was reported in humans to last 5 days (56). In dogs, our recommendations for the NSAID treatment during an aggravated, more obvious painful period, would be at a minimum of 3–5 days -or longer- until resolved, with the oversight of a veterinarian. A patient with re-occuring flare-ups should remain on long-term administration of NSAIDs to reduce inflammation, that will lead to sensitization and maladaptive pain. The benefits of a more chronic NSAID dose regimen outweighs the perceived risks (54). Owner education on this aspect is necessary to negate potential reservations and increase compliance.

Similar to the above, patients should always be assessed for improvement and monitored for any potential adverse events.

TABLE 2 | Summarized core and secondary treatment recommendations for COAST Stage 2.

STAGE 2	
Core treatment recommendations	
Client education	Disease and progression, assessment and treatment plan
Weight optimization and nutrition	Adequate DHA/EPA supplementation, joint focused diets
Regular exercise	Well-balanced training and suitable daily exercise
Physical rehabilitation	Injury prevention, risk factor identification, muscle strength support
Pain management	NSAIDs, flare up reduction
Secondary treatment considerations	
Chondroprotective joint health support	Additional supplements for joint support

Secondary Treatment Options

Within stage 2, there is a high variability in case presentation. Depending on the presenting clinical signs, secondary treatment options should be tailored to each individual patient on a case-by-case basis. No consensus was reached among the panel members on specific treatment recommendations due to limited evidence and differing clinical approaches resulting from the inconsistency of case presentations. Nevertheless, due to the progression of OA, the development of chronic pain, or acute on chronic flare ups, adjunctive pain medications or treatment modalities may be required. Physical medicine modalities that focus on reducing inflammation and managing pain are suggested to be considered on an individual basis (i.e., photobiomodulation, pulsed-electromagnetic field therapy (PEMF), acupuncture, cryotherapy). Implementing a long-term joint health plan with chondroprotective products is aiming to slow down the progression of the disease, but scientific evidence of efficacy for canine OA is currently still limited. The choice of recommeded chondroprotective product is dependent on the specific case presentation.

A summary of stage 2 treatment recommendations is provided in **Table 2**.

Coast Stage 3 (Moderate OA)

Stage 3 refers to the clinical stage of OA that results in moderate clinical signs and moderate signs of discomfort. Those signs are more consistent and obvious at all gaits and activities, with consistent clinical abnormalities. There are noticeable changes in body weight distribution and limb loading and obvious reduction in use of affected limb(s). Some difficulties in rising or laying down are present. A decrease in ROM is present and muscle atrophy can be seen. Joint thickening may be noticeable. Obvious osteophytes and signs of OA are likely evident on diagnostic imaging (10). This is the stage that most dogs are presented for orthopedic and/or pain evaluation.

Treatment Goals

At Stage 3, the treatment goals are an individualized and effective treatment of these multi-facetted pain states and maintaining a tailored level of mobility for the specific patient based on both patient and client. This includes specific interventions aimed at slowing the OA progression and mobility decline.

Prioritized Treatments

Client education includes all the topics mentioned in the general treatment recommendations for nutrition, weight management, exercise, and regular reassessments.

Specific focus points for education at Stage 3 would be the progression of disease, impact on quality of life, and appropriate pain management. The importance of regular assessments should be emphasized to allow for tracking musculoskeletal changes and response to treatment. Individualized home exercise programs, lifestyle adjustments, and household modifications will require adjustments over time.

At Stage 3, a **formal rehabilitation program** designed by a rehabilitation practitioner is highly recommended if logistics allow. Rehabilitation can ensure appropriate assessment and treatment of pain on a regular basis, aiming to slow down the disease progression with a focus on mobility. A rehabilitation partnership provides support to owners for their dog's debilitating disease. This support can include QoL assessments and discussions. A rehabilitation team will create an individualized program for the patient that may include targeted therapeutic exercises which focus on core strength and posture, maintaining or gaining range of motion, improving overall physical fitness, and strengthening the musculature that is required to provide stability for arthritic joints (44). A rehabilitation team should use the fundamentals of rehabilitation to create a long-term rehabilitation plan that considers the dog's and owner's desired lifestyle. The plan should be patient-centric and based on canine physiological and scientific principles. The dog's initial presentation and progress is based on individual assessment. It must address the degree of tissue damage and healing, pain experienced in rest and during exercise, strength, and desired functional goals. An understanding of the phases of tissue healing, frequent patient reassessments, and clinical reasoning skills to progress treatments appropriately for the individual patient are the cornerstones of a successful rehabilitation program (57). A rehabilitation program at this stage often includes a combination of a home exercise plan in addition to a formal in-clinic rehabilitation program. Effective pain management is the fundamental basis for a successful rehabilitation program and contributes to patient compliance and owner motivation.

Lifestyle and household modifications play an important role at this stage to prevent injury and improve QoL by simplification of obstacles. Examples may include ramps for easier access to stairs/car, baby gates to block off stairs for prevention of falls/injuries, carpet runners or yoga mats over slippery floor to prevent slipping, well-padded dog beds for easier comfort, improved traction with nail covers or grips to prevent slipping and dragging toes, assistive devices such as special harnesses (Help'emUp harness) for improved mobility. Adequate nail trimming is also an underestimated tool to assist with proper biomechanics and appropriate alignment. Improving traction and reducing risk of slipping is further achieved by appropriate trimming of foot fur to allow for pads contacting the floor.

For **pain management**, the use of **NSAIDs** is highly recommended at this stage. NSAIDs are the cornerstone of providing adequate anti-inflammatory therapy for OA (54). The initial protocol is very similar to the stage 2 NSAID description. However, if the response of the 4-week trial is showing favorable results for the pet, the use of NSAIDS will most likely be required on a long-term basis. Most dogs tolerate the long-term use of NSAIDs well, although regular wellness visits, bloodwork, and treatment reassessments are needed.

Long-term use of NSAIDs may produce some questions or concerns from both owners and veterinarians (54, 58). NSAIDs have proven the most effective medication for OA but administration does carry the potential risk for adverse events (gastrointestinal, renal) in particular with patients with pre-existing risk factors. Most common adverse events described in dogs appear to be gastrointestinal related and that is a common cause of concern for veterinarians and pet owners alike (53, 54, 58). In human medicine, it has been recommended to use the lowest effective dose for the shortest time possible (59), but the challenge with this recommendation is the risk for suboptimal pain relief with non-verbal patients in veterinary medicine. One study evaluated the efficacy of ketoprofen at lower than label dose in an acute experimental inflammatory model using a weight bearing assessment tool with results showing analgesic efficacy compared to the control group (60), but overall clinical studies are limited addressing the dose reduction approach. Concerns are that lowering the dose can be quite problematic, considering the limitations of owners (and veterinarians in clinic settings) to adequately assess pain, specifically subtle changes. The need for studies assessing if using concurrent medications that may work synergistically with NSAIDs due to similar pathways are needed to evaluate the potential for dose reductions. A canine study on the non-selective COX inhibitor ketoprofen (61) showed that reducing the recommended NSAID dose by 75%, significantly reduced the measured side effects (glomerular filtration rate, gastro-intestinal lesions) but not platelet aggregation changes, and the reduced dose did provide some OA pain relief, although this was improved in conjunction with tramadol (5 mg/kg/day

TABLE 3 | Non-steroidal antiinflammatory drugs available in Canada with label indication for OA.

Generic name	Brand name	Manufacturer	Indication	Size(s)	Dose
Carprofen	Rimadyl	Zoetis	Relief of pain and inflammation in dogs and relief of signs associated with osteoarthritis.	25, 75, and 100 mg Tablets	4.4 mg/kg PO q 24 h or 2.2 mg/kg PO q 12 h
Deracoxib	Deramaxx	Elanco	Treatment of chronic pain and lameness associated with osteoarthritis.	25, 75, and 100 mg Tablets	1–2 mg/kg PO q 24 h or LED
Firocoxib	Previcox	Boehringer Ingelheim	Control of pain and inflammation associated with osteoarthritis.	57 and 227 mg Tablets	5 mg/kg PO q 24 h
Grapiprant	Galliprant	Elanco	Treatment and control of pain and inflammation associated with osteoarthritis in dogs.	20, 60, and 100 mg Tablets	2 mg/kg PO q 24 h
Meloxicam	Apo-Meloxicam	Apotex	Alleviation of inflammation and pain in both acute and chronic musculoskeletal disorders (dogs).	1.5 mg/mL Suspension	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24 h
Meloxicam	Inflacam	Virbac	Alleviation of inflammation and pain in both acute and chronic musculo-skeletal disorders (dogs).	1 and 2.5 mg Tablets	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24 h
Meloxicam	Meloxadin	Vetoquinol	Alleviation of inflammation and pain in both acute and chronic musculo-skeletal disorders (dogs).	1.5 mg/mL Suspension	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24 h
Meloxicam	M-Eloxyn	Zoetis	Alleviation of inflammation and pain in both acute and chronic musculo-skeletal disorders (dogs).	1.5 mg/mL Suspension	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24h
Meloxicam	Metacam	Boehringer Ingelheim	Alleviation of inflammation and pain in both acute and chronic musculo-skeletal disorders (dogs).	1.5 mg/mL Suspension 1 and 2 mg Tablets	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24 h
Meloxicam	Rheumocam	Merck	Alleviation of inflammation and pain in both acute and chronic musculo-skeletal disorders (dogs).	1.5 mg/mL Suspension	Day 1: 0.2 mg/kg PO q 24 h Maintenance: 0.1 mg/kg PO q 24 h
Robenacoxib	Onsior	Elanco	Control of pain and inflammation associated with osteoarthritis in dogs.	5, 10, 20, and 40 mg Tablets	1–2 mg/kg PO q 24 h

PO, slow-release formulation). The comparison of pain scores to the group given ketoprofen at the label dose was unfortunately not presented. A similar dose-reducing study compared a reduced dose of meloxicam (62) to the recommended label dose, and it concluded that the adequacy of pain control was lower with the reduced dose. This study gradually reduced the dose over time (15% reduction) every 2 weeks. Only the first 15% reduction was tolerated by the majority of the dogs (87%), while further reduction revealed inadequate pain control in some dogs (62). This led the authors to conclude that a small dose reduction may maintain efficacy but does not seem to be consistent and appears to be based on individual responses. This may be difficult to differentiate clinically and will require the owners' ability to appropriately assess pain. The study found minimal adverse events in the recommended label dose group of the study over a period of 100 days. See **Table 3** for OA approved NSAIDs in Canada.

Although all approved NSAIDs in Canada provide recommendations to utilize the lowest effective dose, assessing the adequate efficacy for appropriate pain control remains a significant challenge. Utilizing client-based questionnaires, e.g., Liverpool Osteoarthritis in Dogs (LOAD), can help raise owner's pain recognition awareness and aid in assessing the response to treatment (63).

Secondary Treatment Options

Secondary treatment options are often needed at stage 3 and 4 due to the difficult characteristics of OA pain. Depending on the presenting clinical signs, secondary treatment should be tailored to each individual patient on a case-by-case basis. The pain experience is unique for every individual, as is their response to treatment(s). Factors including a patient's personality, receptor genetics, metabolism, and degree of peripheral and central sensitization, which all serve to emphasize the importance of tailoring treatments to an individual patient.

The multimodal approach can be confusing due to the multitude of options, limited evidence in some instances, and the high variation in individual response in efficacy.

No unanimous consensus was reached among the panel members on secondary treatment recommendations due to limited or variability in evidence, therapy available and differing clinical experiences.

Instead, a summarized review of the most common secondary treatment options are provided.

The order of what, when and how to introduce a new secondary medication or modality to the multimodal approach is dependent on the individual dog, owner, veterinarian, and availability (of modality). In this following section a brief

TABLE 4 | Summarized core and secondary treatment recommendations for COAST Stage 3.

STAGE 3	
Core treatment recommendations	
Client education	Disease progression, regular assessment and adequate treatment plan, QoL, pain management
Weight optimization and nutrition	Adequate DHA/EPA supplementation, joint health focused diets
Regular exercise	Suitable daily exercise, case specific exercises
Physical rehabilitation	Tailored rehabilitation program for muscle strength and joint support
Lifestyle adjustments	Changes for mobility support and injury prevention
Pain management	NSAIDs with individualized multimodal pain management plan
Secondary treatment considerations	
Pharmaceutical medications	Pregabalin/Gabapentin, Anti-NGFmAb
Nutraceutical supplements	Cannabinoids, chondroprotective joint health support (DMOAD)
Modalities	Tailored supportive modalities (see **Table 6**)
Interventional modalities	Joint injections, steroid epidural

summary of options for Stage 3 specific is provided (with more detailed description of those treatment options listed below the Stage 4 category as all options may be relevant for both Stages 3 and 4).

- Gabapentin or pregabalin are usually added as a second line treatment based on the clinical experience of some panel members, when the core treatments are not sufficient to control the patients clinical signs. The evidence for the use of gabapentin (or pregabalin) for OA is limited to non-existent, although it is considered a good additional medication when a neurogenic/neuropathic component is expected (see detailed description in appendix, including the advantages of pregabalin over gabapentin).
- Photobiomodulation (64) and acupuncture (65) are considered appropriate modalities to support the multimodal therapy approach based on subjective outcome measures and clinical experience of some panelists; see detailed description in appendix.
- Some panelists would consider joint injections with platelet rich plasma (PRP) or hyaluronic acid (HA)/triamcinolone at this time if a particular joint is refractory to treatment (66–68).
- Some panelists would consider cannabinoids at this time with veterinary oversight for close monitoring and appropriate selection of a suitable quality product (69, 70).

A summary of stage 3 treatment recommendations is provided in **Table 4**.

Coast Stage 4 (Severe OA)

Stage 4 refers to the advanced stage of OA in which patients demonstrate significant clinical signs and a higher level of dysfunction and pain. The signs are obvious, constantly present, and are significantly affecting the QoL of the dog. Those signs include severely abnormal limb loading and shifting of weight distribution with a reluctance and restlessness when standing; significant lameness with a reluctance to move and marked difficulties in rising and laying down. A limited ROM with crepitus, joint thickening, anatomical misalignment, and advanced muscle atrophy can be seen. Diagnostic imaging will show advanced osteophytes and signs of bone remodeling (10).

Treatment Goals

At Stage 4, the treatment goals are often very individual to effectively treat the multi-facetted pain states and often require a tailored level or expectation of mobility for the specific patient based on both the patient and client. The focus in this stage is the continuing assessment and adequate improvements/maintenance of QoL, including support for both owners and patient.

Prioritized Treatments

Client education includes all the topics mentioned in the general treatment recommendations for nutrition, joint health focused diet, omega 3 FA, weight optimization, exercise, and regular reassessments. Stage 3 specific education recommendations also apply. Specific Stage 4 focus points for education would be the impact on QoL as the disease progresses, as well as the importance of appropriate pain management and pain assessments. Regular orthopedic assessments should be emphasized to allow for tracking musculoskeletal changes and treatment results. Muscle wasting is a large concern especially for seniors that are already challenged with sarcopenia (29). Maintaining and possibly building muscle mass is one of the priorities for these patients. Creating a regular exercise and activity schedule that can be modified depending on the health of the dog is crucial. Regular, short, but frequent, low impact walks, and exercise (to tolerance of patient) even at this advanced stage are very important for preservation of mobility, physical and mental health.

At Stage 4, a **formal rehabilitation program** designed by a rehabilitation practitioner is highly recommended if logistics allow. Rehabilitation can provide assessments and discussions about QoL as well as appropriately assess and revise the pain management plan in collaboration with the family veterinarian. The owner often requires advanced lifestyle and home modifications to adjust to their pet's level of disability. Based on the same principles described in Stage 3, a rehabilitation team will create an individualized program for the patient that may include targeted therapeutic exercises which focus on core strength and posture, maintaining or gaining range of motion, improving overall physical fitness, and strengthening the musculature that is required to provide stability for osteoarthritic joints. This often includes a combination of a home exercise plan in addition to the formal in-clinic rehabilitation program and considers the lifestyle and ability of the owners.

Lifestyle and household modifications play an important role at this advanced stage and are similar to the modifications mentioned in Stage 3. These modifications focus on preventing any slipping and injuries and providing more comfort for the dog to ensure that QoL is maintained. Examples are the same as in Stage 3 with the addition of assistive mobility devices that may be helpful based upon the individual case situation. Supporting ongoing environmental enrichment and promoting the human-animal bond plays a role here.

For **pain management** the use of **NSAIDs** continues to be most highly recommended at this stage to keep the patient comfortable. If no co-existing diseases are present, lifelong administration is necessary. As patients are often older at this stage of disease, it is important to continue to monitor for the development of other diseases (kidney, liver, cancer) by regular bloodwork assessments and physical examinations. When NSAIDs are initiated, the same protocol as described in stage 2 and 3 applies. Other anti-inflammatory options may need to be discussed when dogs at this advanced stage have co-existing disease that prevent regular NSAID use. A discussion with owners may be initated to address QoL with aspect of efficacy of NSAIDs over risks of adverse events when no other treatment options provide adequate pain relief to prevent suffering of the animal.

Anti-NGF monoclonal antibody (mAb) is not yet available in Canada at the time of the preparation of this document, however we have included it in the guidelines due to its recent Canadian label approval (Feb 2021). Anti-NGF mAb has demonstrated potential in research and there has been clinical experience in the European market for use in late-stage OA (71–75). Nerve Growth Factor (NGF) and inflammatory mediators (cytokines, prostaglandins, etc.) play an important role as pain initiators and nerve sensitization in chronic pain (50, 76, 77). NGF is largely responsible for the neurogenic inflammation component in chronicity and severity of pain and, it regulates pain through nociceptor sensitization. The mechanisms of NGF on the pain signaling pathway are complex, involving various other receptors and are in parts responsible for the development of neuropathic pain and pain modulation peripherally and in dorsal root ganglion. Anti-NGF mAb blocks NGF from binding to the tropomyosin-related kinase receptor (TrkA) and p75 neurotropin receptor (NTR), subsequently inhibiting the pain signaling pathway potentially treating and slowing down peripheral nerve sensitization (78–80). It has shown to provide OA pain relief over the period of about 4 weeks after a single subcutaneous injection. The safety profile of bedinvetmab, the first anti-NGF mAb to be commercialized for dogs, appears to be high (75). Mild reactions at the injection site (e.g., swelling and heat) may uncommonly be observed. There are no safety data on the concurrent long-term use of NSAIDs and bedinvetmab in dogs. In clinical trials in humans, this has been reported as a potential source of rapidly progressive OA, the incidence increasing with high doses and in those human patients that received long-term (more than 90 days) NSAIDs concomitantly with an anti-NGF mAb (81). Dogs have no reported equivalent of the human rapidly progressive OA.

Once available, Anti-NGF mAb would be recommended as a core treatment for Stage 4 in particular (and possibly earlier) if the pain is refractory to treatment, suggesting that a neurogenic component from nerve hypersensitivity is present. The potential for Anti-NGF mAb to specifically treat the neuropathic or neurogenic component is promising and can be well-incorporated into a multimodal approach. A recent multicentre prospective efficacy study in clinical canine OA patients showed promising results as an additional option in the treatment of pain with seemingly remarkable safety profile. After 3 months of comparative study between a placebo ($n = 146$) and bedinvetmab ($n = 141$) with a treatment success rate (as defined by study criteria) varying from 50% (day 14) to 67.9% (day 56), the treatment success rate stabilized at about 75% over the continuation phase (up to day 252) (75). Clinical experience in the future will give more insights into this medication for OA in dogs as part of a multimodal treatment plan.

Secondary Treatment Options: (Stage 4)

Secondary treatment options are usually needed at Stage 3 and 4 due to the difficult characteristics of OA pain. The pain experience is unique for every individual, and accordingly as is their response to treatment(s). Factors including a patient's personality, receptor genetics, metabolism, degree and mechanisms of peripheral and central sensitization, which all serve to emphasize the importance of tailoring treatments to an individual patient.

However, the multimodal approach can be confusing due to a number of factors. Often the sheer number of treatment options can present challenges, the wrong application of therapies, a lack of understanding of the mechanismus of pain or modality, limited evidence, and the high variation in individual response in efficacy.

Most of the secondary treatment options could be considered in stage 3 or 4, as the order on what, when and how to introduce a new medication or modality to the multimodal approach is dependent on the individual dog, owner, veterinarian, and availability (of modality).

As mentioned previously, the secondary therapies did not receive unanimous support from the panel, the lack of support or difference in opinion often arose due to concerns in prioritization, variability or lack of scientific evidence, lack of experience with therapy and lack of clinical experience. Thus, each treatment below is presented in the context that limitations are present, and thus using clinical judgement to conduct a risk:benefit analysis for therapy is important prior to using it in a patient.

In this section a brief summary of options for Stage 4 specific is provided. The secondary treatment options recommended at Stage 3 apply and may have already been introduced.

- If gabapentin has been ineffective, a switch to **pregabalin** can be made based on clinical experience.
- After introducing pregabalin/gabapentin in Stage 3 in cases with presumed neurogenic/neuropathic hyperexcitability component of the pain, some panelists turn to amantadine as a third line treatment option. Evidence for efficacy in OA is limited, the only paper available provides questionable evidence of its effectiveness (82). Nevertheless, the mechanism of action of blocking the NMDA receptor may warrant its use

TABLE 5 | Summarized core and secondary treatment recommendations for COAST Stage 4.

STAGE 4	
Core treatment recommendations	
Client education	QoL discussion and pain management, regular assessment, owner support
Weight optimization and nutrition	Adequate DHA/EPA supplementation, joint health focused diets
Regular exercise	Suitable daily exercise, case specific exercises
Physical rehabilitation	Tailored rehabilitation program for muscle strength and joint support, mental stimulation and QoL support
Lifestyle adjustments	Mobility and QoL support, injury prevention
Pain Management	NSAIDs, anti NGF mAb, individualized multimodal pain management plan
Secondary treatment considerations	
Pharmaceutical medications	Pregabalin/Gabapentin, Amantadine
Nutraceutical supplements	Cannabinoids, chondroprotective joint health support (DMOAD)
Modalities	Tailored supportive modalities (see **Table 6**)
Interventional modalities	Joint injections, steroid epidural

in cases with pain hypersensitivity in conjunction with other pain medications. With similar evidence, **tramadol** can also be considered in association with an NSAID (61). See detailed description below.

- Some panelists would maintain photobiomodulation, acupuncture and PEMF therapy as supportive modality in the multimodal approach. See detailed description below.
- Some panelists would consider joint injections for joints that are refractory to treatment. See detailed description below.
- Some panelists would consider steroid epidural if indicated, especially for severe lumbosacral pain in conjunction with significant hind-end weakness. See detailed description below.
- Some panelists would consider starting or continuing cannabinoid medicine with appropriate veterinary oversight. See detailed description below.
- Some panelists would consider shockwave therapy (83, 84) as an added physical therapy modality. See detailed description below.
- Even though surgical intervention (arthroscopy, arthrodesis, *etc*.) was beyond the scope of this article, it is important to note that it may be warranted and considered in some cases of both Stage 3 and 4 to provide the needed relief of discomfort, following full recovery from said surgery. An informed discussion of the impact of surgery on both advantages and potential risks and disadvantages (including slower and less comfortable recovery period) is necessary, when performing surgery on an already heavily sensitized joint in a COAST OA stage 4 dog.

A summary of stage 4 treatment recommendations is provided in **Table 5**.

Secondary Treatment Options for COAST Stages 3 and 4

The below information entails Stage 3 and 4 secondary treatment options with more detailed information including MOA, supporting literature and dosing information. They are grouped in categories and not ranked in preference of treatment.

Pharmaceutical Options

Gabapentin is often used as a second line treatment in chronic pain, including OA, in conjunction with NSAIDs, and is commonly added when a neuropathic pain component is suspected (85). The complete mechanism of action of gabapentinoids (gabapentin and pregabalin) has not been fully elicited, but its primary mechanism of action involves the presynaptic inhibition of voltage-gated calcium channels, which in turn blocks calcium influx, that would have led to the release of excitatory neurotransmitters. Due to the inhibition of the excitatory neurotransmitters, there is a decrease in pain signaling across the synapsis. Voltage gated calcium channels (VGCC) are upregulated in a chronic neuropathic state and gabapentin may influence the number of available and active calcium channels. Gabapentin has other, less understood mechanisms of action. These mechanisms are the antagonism of (but not direct binding to) the N-methyl-D-aspartate (NMDA) receptor, also known to be a calcium channel when activated. The antinociceptive effects of gabapentinoids have further been described to be associated with the noradrenergic and serotonergic activity *via* the descending pain pathway (86, 87). For dogs, there are no currently licensed veterinary products in Canada. Studies on efficacy of gabapentin for pain have been disappointing, as the evidence that gabapentin is efficacious to treat pain, in particular inflammatory pain, is low. Clinically it has been noted that gabapentin seems to show better effects when the patient has a neuropathic hyperexcitability component to their pain (significant central upregulation or nerve related pain). Dogs in late-stage OA commonly have a neurogenic inflammatory and central sensitization component and may exhibit back pain due to posture abnormalities and muscle atrophy related to the ongoing OA. The role of both gabapentin and pregabalin would theoretically reduce those components (88), but the evidence for the clinical efficacy has yet to be proven for OA. Recommended dosing is controversial and may depend on age and health status of the dog as well as co-administered medications. A pharmacokinetic (PK) study in greyhounds after a single dose administration concluded a dose of 10–20 mg/kg TID is required to reach plasma levels that compare to adequate levels for pain relief in humans (89), but no canine studies have been able to establish the plasma levels that provide analgesia or the PK results after long-term use. Clinically a 5–10 mg/kg TID dose prevents the unwanted side effects of significant ataxia, sedation, and urinary incontinence. Even though these side effects may be transient, they commonly affect an owner's compliance, and the panel members generally refrain from escalating doses beyond this, in particular in older dogs with pre-existing hind end weakness. Gabapentin is rarely used as a sole analgesic in veterinary medicine, and until there is better efficacy data, it should be used based on an individual assessment as part of a multimodal regimen.

Pregabalin is the gabapentinoid, that has preferable PK and pharmacodynamic (PD) profile over gabapentin (90). The oral bioavailability and duration of action is superior to gabapentin, and the binding to the delta subunit of the voltage-gated calcium channel is stronger, showing higher efficacy in humans (91). The recommended dose based on a canine PK study is 3–5 mg/kg BID (90). In conjunction with an NSAID, pregabalin (and presumably gabapentin) appears to be more effective in human OA studies addressing both the inflammatory and central neuropathic aspects of chronic OA (92). Beyond the recommended dose, pregabalin can have similar side effects as Gabapentin in older dogs.

Amantadine was considered as a third line treatment in refractory pain cases by the panel. Amantadine is an NMDA receptor antagonist and has the potential to be effective in reducing the wind-up effect in patients that show signs of central sensitization (refractory pain despite treatment, sensitive to touch). However, based on the current understanding of the mechanism of action, it does not likely work as a sole analgesic, and is usually recommended to be used in conjunction with an NSAID. Currently there is only one study assessing the efficacy of amantadine in OA pain in dogs (in addition to meloxicam, at a dosage of 3–5 mg/kg SID PO), and it showed incomplete and questionable beneficial treatment effects with a 3 week delay in onset (82). The current dose recommendations for dogs are 3–5 mg/kg BID which are based on a combination of a PK study that involved five Greyhounds (93) and extrapolations from human data. Due to the shorter $T_{1/2}$life in dogs, the historically suggested once daily dose has been adjusted to twice daily (every 12 h) in dogs (93, 94). The PD effects, in particular the efficacy for pain, and adequate plasma levels that would be needed for analgesia have not been established and therefore the evidence for the use of amantadine as a pain medication in dogs with OA is low to non-existent. A study to determine the effectiveness of amantadine for pain in veterinary species is needed. Side effects are usually reduced appetite or vomiting, which in parts may be due to the bad taste of the formulation.

Acetaminophen has been infrequently suggested as a pain medication for dogs with OA. Under the name paracetamol it is more commonly used in Europe. Acetaminophen has a unique mechanism of action related to the endocannabinoid system (ECS). It produces a metabolite (N-arachidonoylphenolamine), which inhibits the enzymatic (FAAH) breakdown of anandamide, inhibits COX1 & 2, and is a TRPV1 agonist. This metabolism pathway may be species-specific and dose dependent but is a promising therapeutic avenue and reflects the interaction of the ECS in a variety of mechanisms of action of pain medications. Clinically human studies repeatedly suggest NSAIDs are superior for pain relief in OA (95) concluding acetaminophen to only play a role in the early-stage mild OA pain relief. Experimental research with induced synovitis study in dogs confirmed that the NSAID carprofen was superior to an acetaminophen-codeine product and that both the PK and PD of acetaminophen may not be sufficient for adequate pain relief and improvement of function (lameness) (96). It has to be noted that the study focused on the anti-inflammatory capacity of both treatments over a very short period of time (9 h) in a chemically-induced model. A long-term clinical study in dogs with OA would be needed to gain more insights, including its side effects and potential long-term effects on liver.

Tramadol. The role of tramadol in treatment of chronic pain has been controversial. Its mechanism of action in dogs is mainly *via* the descending pathway by means of norepinephrine and serotonin re-uptake inhibition. This descending pathway does play an important role in modulating the ascending pain signals. Tramadol seems to have a lack of measurable efficacy for OA in dogs as a sole agent (97, 98). In both studies, the duration of treatment was unusual short and the OA stage advanced (radiographically present) [10 days: Budsberg et al. (98); 14 days: Malek et al. (97)]. The analgesic efficacy of a NSAID-tramadol combination looked more advantageous over a 4-month period, including a 4-week daily initial regimen administration (61). The PK profile of tramadol is also not ideal in dogs (99), making a slow-release formulation (5–10 mg/kg PO daily) more attractive. Long-term use has been reported to have a decrease in effect (94). The concerns of gastric adverse effects in conjunction with NSAIDs due to the serotonin modulating gastric acid secretion and contributing to gastric lesions, have been assessed with no evidence to detect any deleterious effects (61, 100). Further studies are needed to investigate the effects of tramadol, as there may be emotional benefits contributing to pain control and QoL through the serotonin/dopamine and norepinephrine pathways (requiring more exposure to treatment to induce changes). These pathways on the other hand may also contribute to the negative behavioral side effects that one may see in some (senior) dogs. Based on current literature, tramadol plays a minimal role in the treatment of OA in dogs. More research is needed to further assess tramadol and its role in chronic pain in dogs.

Nutraceutical Options

With the recognition that pet owners are increasingly looking for botanical and "more natural" treatment options, as well as an increase in interest from the scientific veterinary community in the nutritional and medicinal use of herbal medicinal products, the expert group felt it important to include products and ingredients that have appropriate studies and evidence for OA treatment (101, 102). The list is not complete but includes some of the more common product groups.

It is important to recognize that nutraceutical combination products fall under the category of Animal Health Products, which are very differently regulated than the pharmaceutical industry (103), currently not requiring research or safety studies, but also cannot claim therapeutic benefits. When considering a specific product, it is important to assess specific ingredients and their concentrations. A certificate of analysis can be obtained, that shows a product is free of contaminants like residual solvents, heavy metals, microbials, pesticides, or fungus. Ideally a company can also be transparent about quality of product, source of ingredients and manufacturing standards. A natural product number (NPN), that is provided for a licensed natural health product assessed by Health Canada to be deemed safe, effective and of high quality, adds to assurance of quality. To date there is little information about the stability of products, ingredient interaction, bioavailability or PK profile, including dosing for most natural health products (103). Another area of needed research is the effects of using certain nutraceutical products together with other nutraceutical or pharmaceutical products, especially when the mechanism of actions works on similar pathways or receptors, or the metabolism is impacted. In general, a synergistic or additive effect is presumed, but scientifically not established for most products. Close monitoring for efficacy and adverse events is recommended as has been previously suggested for multimodal pain management.

b.1 Cannabinoids. The endocannabinoidome system is involved in almost all aspects of the ascending and descending pain pathway at all major signaling points including the periphery, spinal cord and CNS. The endocannabinoidome system extends from the ECS system (receptors (CB1 and 2), enzymes and ligands) to other classic receptor systems that are part of the pain pathway (opioid, TRPV, serotonin, prostaglandins, etc.). Cannabinoids have been shown to play a role in neurogenic and inflammatory pain by a variety of mechanism of actions on various receptors and pathways (104). The use of cannabinoids in veterinary medicine is still relatively new, nevertheless there have been multiple clinical trials published that show promising results for its efficacy for pain relief of OA (70, 105–110). The existing studies conducted have been product specific, in that the researched product has a specific cannabinoid and terpenoid profile. Unfortunately, this makes it challenging to extrapolate and interpret the results of PK and PD toward other comparable products (69, 70, 107, 111). The safety profile needs further investigation, particularly with regards to causes of liver enzyme elevation and its effects on liver function (107, 110). Current regulations in veterinary medicine make it difficult for veterinarians to support owners with finding a consistent product that can be safely used in their pet. From clinical experience, a cannabidiol (CBD) isolate product may not provide adequate pain relief in moderate to severe OA cases but can be useful in mild cases (110, 112). A full spectrum CBD|THC product has been shown to be more effective in advanced pain cases based on the nature of pain (inflammatory, immune-mediated, neurogenic). The role of THC/THCA and CBD/CBDA as a CB2 receptor agonist in more severe or immune mediated pain is still to be further investigated in dogs but would presume to play a role based on research from other species (113–115). Like other medications, cannabinoids used for OA pain should be accompanied by regular wellness evaluations, blood work and monitoring for patient response or adverse events, as synergistic effects can be noted when used together with other medications due to overlapping mechanism of actions and changes in metabolism (112).

b.2.Chondroprotective agents:

Due to the destruction of cartilage as part of the disease process in OA, the search for biological substances with the ability to restore the damaged connective tissues and protect the cartilage and chondrocytes is ongoing. These substances are considered chondroprotective agents and if effective are termed disease-modifying osteoarthritis drugs (DMOADs) (116). Currently there is still a discrepancy between *in-vitro* and *in-vivo* studies, in parts due to the lack of medications that have proven adequate oral bioavailability and distribution to site of cartilage. Commonly considered chondroprotective agents that have been assessed in clinical trials and research studies, although with often limited conclusive results, include glucosamine hydrochloride (or sulfate), chondroitin sulfate, avocado soybean unsaponifiables (ASUs), egg-shell membrane extract, sodium pentosan polysulfate (PPS), green lipped mussel extract, type II Collagen (UC-II), and elk antler velvet extract among others.

b.2.1 Glucosamine and chondroitin have been suggested to have chondroprotective effects and are commonly used for OA patients in both human and veterinary medicine. Yet, inconsistent study design among studies has resulted in limited and conflicting results (117), causing questioning of their actual efficacy in veterinary species. In brief, based on *in-vitro* data, glucosamine is partly responsible for the regulation of collagen synthesis in cartilage and it contributes to glycosaminoglycan and proteoglycan synthesis (118, 119). Chondroitin sulfate is a sulfated glycosaminoglycan and contributes to extracellular matrix of cartilage and adds resistance and elasticity to the cartilage (120). The role of chondroitin sulfate is the inhibition of specific destructive enzymes in joint fluid and cartilage and, like glucosamine, contributes to the synthesis of glycosaminoglycans and proteoglycans (119, 120). The biggest challenge that both chondroitin sulfate and glucosamine face are low oral bioavailability and inconsistencies in product formulation (strength, form for glucosamine as sulfate vs. hydrochloride, and other ingredients added to the product), both contribute to the inconsistent results found in efficacy evaluation in literature and clinics. Most veterinary products contain glucosamine hydrochloride, which has significantly less bioavailability in humans than glucosamine sulfate. Pharmacokinetic studies are limited (121, 122) and the dosing recommendations of 15–30 mg/kg seem arbitrary and have not been established based on pharmacological evidence. The study performed by Adebowale et al. (123) demonstrated an oral bioavailability of 12% for glucosamine hydrochloride and 5% for chondroitin sulfate. Despite the differences in clinical studies from a point of view of design, products and results, there have been some well-conducted studies that provide more insight into the use of glucosamine and chondroitin (124–131). These studies evaluated joint function, comfort of the patient, and the overall safety profile of the supplement. The various outcome measures were aimed at establishing the potential anti-inflammatory and presumed mechanical improvements due to advanced cartilage function, with some positive results. The follow-up ranged from 2 to 6 months, with dosing around 40–62.5 mg/kg/d for glucosamine hydrochloride and 12–50 mg/kg/d for chondroitin sulfate in dogs, doubled for cats (132). No improvement was observed with objective outcomes in any study, and mild improvement was observed with non-validated subjective clinical scoring at three time-points in one study [Day 90, 120, and 150 (129)] and in one time-point in another study [Day 70 (127)]. Little is known about the actual effects of glucosamine and chondroitin at the level of the joint in either late or early stages of OA (133, 134). Canapp et al. showed evidence of protective effects of glucosamine hydrochloride with chondroitin sulfate at the level of joint, when given preemptively in an induced synovitis study (135), which would be different from OA. Despite the concerns about the lack of evidence in this category, owners and veterinarians alike continue to use or recommend products that contain glucosamine and chondroitin, often due to the high safety profile of most products. Education is important to clarify understanding and expectations of these products, in addition further studies including systematic review and metanalysis are required, to help resolve concerns of bioavailability and ultimately, efficacy.

b.2.2 Avocado soybean unsaponifiable (ASUs) is a mixture of the unsaponifiable fractions of one-third avocado oil and two-third soybean oil, that had promising effects for OA as a nutraceutical (136). The mechanism of action has been suggested to be inhibitory on interleukin-1 (IL-1) and stimulating on collagen synthesis based on *in-vitro* articular chondrocyte culture study (137). A potent inhibition of IL-8 and PGE_2 has also been suggested (138). Cartilage repair may be promoted by its action on subchondral bone osteoblasts by preventing the osteoarthritic osteoblast-induced inhibition of matrix molecule production. Clinical studies in human OA with a focus on pain reduction outcomes show positive but limited evidence (139). A structural assessment study was done in a canine cruciate model, which demonstrated that ASUs reduce the development of early osteoarthritic cartilage and subchondral bone lesions. The suggested mode of action was mediated by the inhibition of inducible nitric oxide synthase and matrix metalloproteinase 13 (MMP-13), both key mediators of structural changes in canine OA (140). Dosing used in this study was 10 mkg/kg/day over 8 weeks. A study by Altinel et al. (141) evaluated ASU administration based on joint fluids and saw an increased levels of transforming growth factor beta 1 and 2 (TGF-ß1 and 2), both considered to be associated with the chondrocyte production of collagen and proteoglycans. Dosing for this study was 300 mg/dog SID, which translated to about 12 mg/kg. One clinical trial was conducted to assesses the efficacy of ASU in conjunction with glucosamine and chondroitin (131), not showing a significant difference in results, which may possibly be due to relatively low dosing (2.5–4.5 mg/kg/d). Overall, the evidence for ASU having beneficial effects in canine OA is limited but so far positive for both symptom relief and potential chondroprotective effects, although product differences need to be considered.

b.2.3. Egg-shell membrane (ESM) is the mesh-like bilayered substance that is found between the calcified shell and the albumin in chicken eggs. It is primarily composed of fibrous proteins such as collagen type I, keratin and elastin and glycosaminoglycans (142, 143). Egg-shell membrane extract has been evaluated *in-vitro* and showed an inhibition of IL1 β and tumor necrosis factor alpha (TNFα) (142, 144). A clinical study with a commercial product showed some positive effects on symptom relief that was detectable after 1 week and lasted throughout the study period of 6 weeks but lacked the statistical significance. The study further detected a change in serum levels of the cartilage degradation biomarker, c-terminal cross-linked telopeptide of type-II collagen (CTX-II) and concluded to a chondroprotective aspect (145). Dosing in the study was 300 mg/dog daily (equivalent to about 13.5 mg/kg daily), extrapolated from the effective studied human dose of 500 mg/day). Another study that examined the effect of a commercial ESM product in dogs with hip dysplasia found a clinical benefit of symptom relief at 15 mg/kg/day (143). Finally, another commercial ESM product was recently tested (146), and the dosing regimen was as per package (soft chews) recommendations, but a mg/kg dosing information was not made available. If the changes were in favor of the treated group, the differences did not reach statistical significance. Egg shell membrane supplements may be an option for symptom relief, however its role in chondroprotective measures and its pharmacokinetic profile require future studies to be completed.

b.2.4. Systemic DMOADs – Pentosan polysulfate sodium (PPS) is a polysulfate ester of xylan, prepared semi synthetically from beechwood plant material and is structurally similar to glycosaminoglycan (147). The mechanism of action may be a stimulation of hyaluronic acid and glycosaminoglycan synthesis, inhibition of proteolytic enzymes including metalloproteinases, and free radical scavenging as well as reduction of cytokine activity and osteoclast differentiation (147–149). The sodium derivative of PPS [sodium pentosan polysulphate (NaPPS)] has been available in veterinary medicine, is administered in the form of a subcutaneous injection and has been approved as a DMOAD, but its efficacy has not been fully established in the literature and remains controversial among clinicians. A canine post cruciate surgery study saw a faster recovery in one outcome measure compared to the placebo (150) and a clinical human study with knee OA found significant improvements in symptom relief compared to the placebo group (147). Yet clinically the results in dogs are inconsistent. Some patients demonstrate mild to moderate improvement, while others show no response. More studies are needed to assess the clinical and chondroprotective effects in dogs.

b.3. *Boswellia Serrata* (also known as "true" frankincense) has been included in many anti-arthritic joint supplements and has been shown to have anti-inflammatory properties in published studies (151). It has been traditionally used for centuries for this purpose (152). The active ingredient from the tree is the oleo-gum resin, and it is harvested by collecting the sap of the tree, then it is processed for use (stored, solidified and graded) (151). *Boswellia* resin is a traditional remedy for multiple ailments, but its anti-inflammatory properties held therapeutic interest and have been further explored. One of the mechanisms of action for its anti-inflammatory property is the inhibition of leukotrine (5HETE and leukotrine B4) synthesis by blocking the 5-lipoxygenase. It also has been shown to reduce glycosaminoglycan degradation, inhibition of TNF α and IL-1 β *in-vitro* (153). As with many of the other nutraceutical ingredients, the oral bioavailability in dogs can be challenging and species-specific PK studies are needed (154). Product formulation and manufacturing techniques also play a role in efficacy and safety. There have been some clinical studies in dogs (155) and humans (156), and *Boswellia* seems to have a wide safety range, based on acute and chronic toxicity and safety studies. However, dose determination research is needed, as the dose in one canine study was

TABLE 6 | Potential modalities discussed in this paper that may be added to an OA treatment plan to support the individual patient.

Potential modalities to support OA treatment plan
Acupuncture
Photobiomodulation
Pulsed ElectroMagnetic Field therapy (PEMF)
Extracorporeal Shock Wave therapy (ESWT)
Joint injections
Steroid epidural

40 mg/kg, but others have suggested 50–100 mg/kg once daily (155).

Other and combination products: Products that combine different nutraceuticals are available and popular among pet owners. There are commercially available products as well as veterinary specific products that have been scientifically assessed with promising results: omega-3 FA, including green-lipped mussel, products are the most recognized (34, 35). *Curcuma* efficacy alone (157), or in combination with collagen and green tea extract in an enriched therapeutic diet (158) did not show clear results. However, multi-herbal, omega-3, glucosamine combination in two different formulations (124, 159) was more convincing. Specific ingredients in combination products with promising efficacy shown in studies include epiitalis (160, 161), undenatured type II collagen (UC-II) either alone (128, 162–164) or in combination with other chondroprotective ingredients (128, 129, 163), and warrant mentioning and further research.

Finally, promising natural health products, such as elk-velvet antler (165) or the *Brachystemma calicinum* D. don Chinese plant (166, 167), that have attractive analgesic benefits currently have a minor role in commercialization due to their controversy in safety and quality control production.

Other Modalities

Under this category, there are specific modalities that are commonly used clinically in OA patients and have been scientifically evaluated (**Table 6**). We provided a summary but encourage the reader to further their own knowledge with additional research on available studies, bias, risks, side effects, techniques, required level of training or certification process, and benefits. These details were beyond the scope of this paper, but are important information, when considering the different modalities. The list of OA related modalities presented in these guidelines is not exhaustive, additional modalities may be considered by experienced and trained practitioners (including osteopathy, chiropractice, canine massages, cryotherapy, therapeutic ultrasound among others), and should also be based on available evidence that results from appropriate study design.

Photobiomodulation (Laser) treatments can potentially be beneficial for some patients, using appropriate settings for specific tissues or conditions. There have been significant knowledge gains in the field of laser therapy over the last 10 years and it is important to understand the technicalities to assure that the targeted tissue depth is reached, as it will vary depending on tissue (168, 169). The mechanism of action of Laser (light amplification by stimulated emission of radiation) is on a cellular level *via* photobiomodulation. Investigators have shown that laser application on tissue has multiple effects including an increase in angiogenesis, neurite extension, normalization of ion channels, stabilization of the cellular membrane, and other cellular changes (170), but the most recognized mechanism is the nitric oxide (NO) interaction in the cytochrome C system leading to improved ATP utilization and production. Reducing inflammation and edema through means of IL-1 reduction, acceleration of leucocyte, and inhibition of PG synthesis have also been discussed. In veterinary medicine Low Level Laser therapy (LLLT) can be useful in the treatment of musculoskeletal pain (170) using either a class IIIB or IV laser. Usually, wavelengths in the therapeutic window between 600 and 1,100 nm are used, with adequate penetration into tissue requiring a minimum of 800 nm. Laser therapy can reduce muscle tension when used for surface area application, however treatment of OA *via* intra-articular penetration of the laser beam requires a higher power (higher than 4–8 J cm^2) or a longer duration of treatment. The risk of burns at the higher wavelengths are avoided by constant movement of the probe, extra precautions with darker skin/fur animals as the absorbed light in these patients may produce warm energy. At times shaving thicker fur may improve wavelength penetration. Laser therapy is used as an integral part of rehabilitation protocols (64, 170, 171) and is commonly used as an add on modality to an overall sound treatment plan. It appears that with better understanding of laser therapy and better designed studies, the knowledge for its usefulness in the treatment of OA has improved (64, 169, 171–174) but it is not yet conclusive (175). It will require further extensive and appropriate investigations to answer its benefits, risks, limitations and settle the strong controversy surrounding this modality.

Acupuncture can be an effective conservative treatment for neuro- and musculoskeletal pain conditions including OA and is recommended as an adjunct therapy within the multimodal approach (176). Various studies have been published in dogs with OA with different outcome measures and assessments, as well as acupuncture techniques and results. The changes that have been noted seem subtle but positive, although not always statistically significant. Acupuncture is a modality that seems to have an individual response irrelevant of whether a Western or Eastern approach is used. Extensive human studies have shown a beneficial effect of acupuncture in the treatment of OA (177), but metanalyses are not always conclusive and the claimed small analgesic effect cannot be clearly distinguished from bias (178). Veterinary studies are not different (65), in parts due to the difficulties in pain assessment and the challenges of standardizing a treatment protocol. The differentiation of electroacupuncture vs. dry needle acupuncture is one of the questions that would be interesting to have answered. Acupuncture is a highly individualized therapy that is commonly used within a rehabilitation program or as part of palliative care, continues to gain popularity within the veterinary community.

Mechanical stimulation: Pulsed ElectroMagnetic Field therapy (PEMF) **and Extracorporeal Shock Wave Therapy**

(ESWT). **PEMF** is an emerging area of interest for OA treatment in both human and veterinary medicine (179). PEMF utilizes frequencies at the low end of the electromagnetic spectrum (6–500 zH), which stimulate biological effects on a cellular level. The mechanism of action remains not fully understood but potential mechanism of actions of PEMF are the stimulation of chondrocyte proliferation and differentiation, as well as extracellular matrix synthesis. PEMF can cause a decrease in inflammatory cell infiltration, reduction in immuno-positive cells to IL-1β, decrease in TNF-α, and increase TGF-β 1 (promoting cartilage repair). PEMF shows promising results in both *in-vitro* and *in-vivo* studies to provide pain relief, improved function and slowing down the progression of OA (180, 181). Although literature is readily available, the quality of veterinary studies on PEMF are still limited (182) and more research needs to be conducted. As an adjunct, non-invasive therapy, this modality will likely play an increasing role in clinics and, especially for in-home use in form of commercially available loops, discs, and mats (182). **ESWT** is a special, non-linear type of pressure wave with a short rise time (around 10 μs) and a frequency ranging from 16 to 20 MHz. Different ESWT units are available with different wave forms (radial, piezioelectric and electrohydraulic) which will lead to different tissue penetration of the acoustic wave. Extensive knowledge and training is needed for appropriate application of this modality. In particular the electrohydraulic waves will require sedation of the patient, potentially part of the reasons why this modality is less mainstream in veterinary practice. Several studies have demonstrating attractive value of ESWT in managing canine musculoskeletal alterations, mostly OA, either for stifle (183), shoulder (184) or hip (83, 185) joints.

Joint Injections

As part of "regenerative medicine," joint injections of "orthobiologics" or drugs have been explored for local pain relief of a specific joint. Severe OA in the elbow, shoulder or hip can be difficult to treat to provide adequate comfort. Injections of hyaluronic acid (HA), mesenchymal stem cells (MSC) or platelet-rich plasma (PRP), autologous protein solution (APS) have been proposed and investigated. This panel has agreed that as of now, most of the research in canines has been published with PRP injections (see below) and is therefore currently the recommended choice, if a joint injection is considered. Stem cell injections have some chondroprotective and regenerative potential, however, are still considered to be in their infancy. Injections of HA and steroids are usually reserved for palliative cases as the pain relief may show benefits for symptom relief, but the chondro-destructive potential remains controversial for steroid injections (186). The use of HA/steroid joint injections in human OA appears to be favorable in the literature due to the improvement of symptoms as well as the joint lubricating effects of HA but has a relative short duration and a limited number of injections per year. It remains quite uncommon in canine medicine (187, 188). The use of HA has been studied either in experimental models (189) or in clinical use in OA dogs (190) with positive outcomes over an appropriate (several months) length of time (67, 68, 191). It has been previously suggested that intraarticular HA would be more effective in dogs with mild to moderate OA than in those with severe OA (189). The combination of intraarticular HA and triamcinolone looks efficient too (187).

Platelet-rich plasma (PRP) is an orthobiologic composed mainly of platelets, which in turn will release growth factors to then stimulate other cytokines and chemokines. Derivatives include autologous platelets concentrate (APC) and APS. The growth factors (platelet-derived growth factor (PDGF), transforming growth factor β 1 &2 (TGF-β 1 &2), vascular endothelial growth factor (VEGF), basic fibroblastic growth factor (bFGF) and epidermal grow factor (EGF) among others) are the driving forces as important bioactive compounds contributing to wound healing by enhancing cellular migration, cellular proliferation, angiogenesis, and matrix deposition, which in turn may counteract cartilage destruction (192, 193). Platelet preparation systems vary in their ability to concentrate platelets, as well as select beneficial cells over unwanted cells like RBC, leukocytes, neutrophiles (193, 194). The ideal concentrations of platelets and WBCs are unknown, and likely depend on the type and chronicity of the injury. In the literature, the high variability in PRP preparations may be the reason for inconsistent results, but emerging clinical and *in vitro* studies, and clinical experience seem promising. PRP preparation can be done by specific systems (commercial gravity systems or centrifuge systems), that can be acquired. The protocol involves a blood draw from the patient which in turn is spun down in a centrifuge to separate RBC and plasma from the platelet/WBC layer. In some instances, a second centrifugation is recommended for further platelet concentration. The final product is then injected meticulously aseptically into the joint to avoid any infection. Duration of pain relief may last from 3 to 12 months and has been reported in OA dogs for PRP alone (195–199) or associated to HA (67) or physical therapy, showing longer duration of analgesia (197), APC (200, 201), APS (187, 202, 203). Most interestingly, PRP may have the potential to slow the progression of the disease, as suggested by a recent metanalysis including 1,251 animals (19 studies on rodents, 13 on rabbits, 4 on horses, one on goats, and 7 on dogs) (204). The disease-modifying effects (DMOAD) were present in 68% of the studies (beneficial clinical effects in 80%) and included attenuating cartilage damage progression, and reducing synovial inflammation, coupled with changes in biomarker levels.

The comparison between intraarticular HA, APC, triamcinolone, and stanozolol supports more prolonged analgesic benefits, with lower variation in results for HA and APC (205). Several reports of beneficial analgesia exist after intraarticular MSC injection (206–212). However, these reports present methodological drawbacks, such as absence of standardization in MSC preparation, either limited power of analysis, and/or subjective outcome measures, or most often lack of a placebo control, to really state about the interest of intraarticular MSC injection. Finally, some anecdotal publications mention the use of intraarticular botulinum toxin A for pain management in OA dogs (213, 214), of Tin-117m (^{117m}Sn-colloid) isotope radiopharmaceutical in canine elbow OA (215), and of intraarticular resiniferatoxin for long-term analgesia (216).

Steroid epidural: Senior dogs especially, but also young working dogs (i.e., German Shephard military or police dogs) may exhibit severe lumbosacral pain. This can be a primary disease, as some dog breeds are predisposed to it, but it also can be part of posture changes related to late-stage OA in hips or knees. The resulting progressive hind-end weakness due to avoidance of muscle usage caused by pain leads to significant mobility issues. An epidural injection of long-acting steroid can provide relief of a duration from 4 to 12 months (217, 218). For an epidural injection, the patient is heavily sedated, or in case of health-related concerns briefly anesthetized. The lumbosacral area is aseptically prepared and 0.1 mg/kg methylprednisolone acetate injected sterile. Complications appear to be rare in veterinary medicine and may relate primarily to sterility and trauma but have also been linked to the formulation (including preservatives and particulation). In human chronic spinal pain management, complications can be severe, and concerns have been raised specifically regarding the use of particulate steroids -like methylprednisoline- when applied epidurally (219).

SUMMARY

The Canadian OA treatment guidelines were created from a diverse group of experts, driven by the shared understanding of the need for providing direction for veterinarians on selecting appropriate therapies based on COAST stage for a patient experiencing OA. Due to the inflammatory nature, chronicity, potential neurogenic component and continued progression of the disease, OA requires a multimodal approach. The treatment options for OA are constantly evolving as new therapies and research emerge, and this document captures the current or soon to be arriving options for Canadian veterinarians in 2022. It aims to provide insights into the treatment choices of experts and is grouped based on consensus into core and secondary treatments.

The panel felt that for every OA patient, their multimodal plan should involve client education, a weight management plan, optimized nutrition including omega 3 fatty acids, exercise, and beginning in stage 2, pain management. Additional secondary therapies or modalities can then be layered on, based on OA stage, individual patient need and veterinarian or pet owner preference. A cautious and rigorous characterization of the pain syndrome affecting the patient must guide the veterinarian to the best choice of therapeutics. With the fundamental understanding that the multimodal approach should always be aimed at slowing the progression of OA, maintaining patient mobility and above all, maximizing patient comfort and QoL.

AUTHOR CONTRIBUTIONS

CM wrote the first draft of the manuscript. All authors contributed to the discussion for the content of this manuscript, wrote sections of the manuscript and contributed to the correctness of the content (in order of their authorship, besides ET, who added significant amount and is considered senior author on this manuscript), and manuscript revision, read, and approved the submitted version.

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Electromyography of the Multifidus Muscle in Horses Trotting During Therapeutic Exercises

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Thoracolumbar pain has been identified in both human and equine patients. Rehabilitation and conditioning programs have focused specifically on improving trunk and abdominal muscle function (1–5). Equine exercise programs routinely incorporate ground poles and training devices for the similar goals of increasing spinal and core stability and strength (6–8). The multifidus muscle has been an area of focus due to atrophy associated with disease (9). To date, there have been no reports on the activity of the multifidus muscle in horses in relation to therapeutic exercises. Our objectives were to use electromyography to determine the average work performed and peak muscle activity of the multifidus in horses trotting, trotting over ground poles, trotting while wearing a resistance band-based training device and trotting while wearing the training device over ground poles. We hypothesized that ground poles and the training device would each increase average work performed and peak multifidus muscle activity. Right and left cranial thoracic locations showed significant increased muscle work and peak activation when horses were trotted over ground poles versus without. The peak activation was significantly greater in horses trotting over poles in both lumbar regions, but there was no significant change in peak activation in either location due to the training device. When the influence of the training device was investigated without ground poles, left caudal thoracic muscle work and peak activity, and right lumbar muscle work were significantly lower when using the training device, as compared to without. When the training device was combined with trotting over ground poles, both left and right caudal thoracic regions showed significantly lower muscle work and peak activity when the device was used. There was no significant difference between with and without the device in either left or right lumbar muscle work. In conclusion, implementing ground poles can be an effective strategy to increase the activation of the multifidus muscle, however, caution should be taken when incorporating the use of a resistance band training device as muscle work and peak activation were significantly reduced in most locations. Further study should be performed in regards to the training device to determine its effects on epaxial musculature.

Keywords: electromyography, multifidus, rehabilitation, back pain, equine

INTRODUCTION

In humans, paraspinal musculature has been shown to contribute a substantial portion of overall spinal stability (10, 11). The multifidus muscle has been specifically identified as a major contributor to spinal stabilization in humans (12). Spinal instability has been correlated to injury, even under low stress movements of daily living (13). Additionally, it has been hypothesized that a build-up of microtrauma could induce changes in neuromuscular control, thus predisposing spinal components to further injury (14).

Lower back pain (LBP) is defined as the pain of the posterior trunk between the 12th rib and the lower gluteal folds (15). A myriad of underlying conditions can cause LBP including but not limited to intervertebral disc herniation, spinal stenosis, degenerative scoliosis, osteoarthritis of the facet joints, and idiopathic causes (16, 17). While horses can have similar symptoms of LBP as seen in humans, the underlying cause is not always as clear. Veterinary clinicians are limited in their ability to diagnose specific spinal lesions in horses due to their size and the difficulty to perform advanced diagnostic imaging. Regardless of the cause of LBP in humans, treatment relies heavily on physical therapy to improve trunk and abdominal muscle function (1–5), as well as proprioception and balance (1, 3, 18). Similar principles have been implemented into equine therapeutic exercise programs with the use of ground poles and other training devices.

Ground poles are routinely used in equine exercise programs to improve proprioception, increase stride length, promote symmetry, and induce joint flexion (6, 7). Brown et al. has shown horses trotting over ground poles successfully clear the obstacle by lifting their limbs higher and increasing joint flexion across all joints (19). There was significantly more joint flexion when trotting over poles as compared to flat ground (19). It was concluded that trotting over poles would be effective to increase activation and strength of flexor muscles. During the stance phase, horses did not show significant increases in vertical ground reaction force or extension of the metacarpophalangeal and metatarsophalangeal joints (20). Thus, the load placed upon each limb was like that traveling across flat ground (20). To date, muscle activity has not been directly reported in horses trotting over ground poles.

Several types of training devices have been developed and used in equine exercise programs. Overall, the intention of these devices is to promote abdominal lifting, engagement of the hind limbs, and spinal stability while strengthening the epaxial musculature (21). One resistance band training device was determined to reduce mediolateral and rotational motion of the thoracolumbar spine (8). The authors concluded that this decrease in thoracolumbar motion was due to increased dynamic stability (8). If human modeling data is extrapolated, this would likely be due to increased muscle activity, since muscles contribute a large part to spinal stability (10, 11). Muscle activity was not assessed in the aforementioned resistance band-based device (8). Cottrail et al. described the activity of the longissimus dorsi muscle while using a different training device (21). The longissimus dorsi muscle is a large epaxial muscle in horses thought to contribute to dynamic spinal stability (22). Cottrall et al. did not find any significant increase in longissimus dorsi activation with the use of the training device (21). Therefore, if either of these training aids improve dynamic spinal stability, another mechanism or muscle is likely to be involved.

Electromyography (EMG) is the study of muscle activity by assessing the action potentials created by the motor unit (23). The activity of deep musculature can be recorded using in-dwelling fine wire electrodes without the potential for cross-talk from other muscles (23). The multifidus muscle can be imaged with routine ultrasonography (9, 24) in order to direct accurate and precise electrode placement.

Our objectives were to use electromyography to determine the average activation performed and peak muscle activity of the multifidus in horses trotting over ground poles and while wearing a resistance band-based training device. We hypothesized that ground poles and the training device would each increase average activation performed and peak multifidus muscle activity.

MATERIALS AND METHODS

Horses

Four horses from the University of Tennessee Veterinary Research and Teaching herd were included. Any horse with greater than a grade 2 lameness based on the American Association of Equine Practitioners lameness scale were excluded. Gaited horses and gaited breeds were excluded unless they maintained a consistent diagonal two beat trot gait. This study was performed in accordance of the Assessment and Accreditation of Laboratory Animal Care and United States Department of Agriculture guidelines with approval from the University of Tennessee Institutional Animal Care and Use Committee.

Gait Cycle Validation

The gait cycle was linked to the activity of the longissimus dorsi muscle. Self-adhesive surface electrodes with an inter-electrode distance of 2 cm were adhered to clipped, shaved, and cleaned skin overlying the longissimus dorsi muscle at the level of the dorsal spinous process of the 16th vertebrae as previously described (22).

In addition to having surface EMG sensors in place, 9 mm spherical reflective markers were placed on the lateral aspect of each hoof at the level of the coronary band. Using motion analysis (Nexus, Vicon Motion Systems, Oxford, England) integrated and synchronized with the electromyographic signal from a telemetric system (Myomotion; Noraxon USA, Scottsdale, USA), the timing of the longissimus dorsi muscle activity in relation to the gait cycle was determined.

Kinematic data from both motion capture cameras and electromyography were collected using Nexus software and imported into Visual3D (C-Motion Inc., Germantown MD, USA) for further processing. Kinematic data were interpolated and low-pass filtered with a frequency cut off of 8 Hz. Gait cycle events of heel strike and toe off of each hoof were labeled based on when makers reached a zero position in the vertical z-plane.

Fine-Wire Electromyography

Muscle potentials from the multifidus muscle were collected using a telemetric unit (Myomotion; Noraxon USA, Scottsdale, AZ) with a sampling frequency of 1,500 Hz. The skin was clipped, shaved, and cleaned using chlorhexidine and isopropyl alcohol. Ultrasound was used to locate and identify each dorsal spinous process. The skin was desensitized with 1 ml mepivacaine per site taking care to remain superficial to the thoracolumbar fascia to prevent alterations in thoracolumbar muscle function as previously reported (18). Briefly, 23 gauge 75 mm length needles with pre-loaded paired electrodes (Chalgren Enterprises, Gilroy, CA) were aseptically inserted through the skin and visualized with ultrasound guidance to into the multifidus at the junction of the middle and deep third (**Figure 1**). The needles were removed, and the hook ended electrodes remained embedded in the muscle. No redirection of the needles was allowed given the potential for damaging the electrode ends. If the intended location was not achieved with the first insertion, the needle was removed and a new pre-loaded needle was used. Electrodes were placed at the level of the dorsal spinous process of the twelfth (T12) and eighteenth thoracic (T18) and fifth lumbar (L5) vertebrae bilaterally. Wires were connected to the EMG sensors using a screw post and nut device (DTS Fine wire lead connector, Noraxon USA, Scottsdale, AZ).

Exercises

Electromyography signals were collected with the horse traveling straight in hand on synthetic arena footing under four separate conditions: trotting over a series of ground poles 10 cm in diameter, while wearing a therapeutic band-based training device (Equicore Concepts, East Lansing MI), trotting over the ground poles while also wearing the training device, and trotting over the same arena surface without either ground poles or therapeutic band exercise device. Distance between poles was approximately one meter, dependent upon the height and natural stride length of each individual horse. Horses were acclimated to the resistance band training device for a minimum of 3 days before data collection. Tension of each of the resistance bands was set to 25% (the length of the elastic resistance band was made to be 75% of the measured distance between the attachment points). The authors find this degree of tension most clinically effective and is comparable to other studies (8). The head and neck were maintained in a neutral position for every exercise. Video recording was synchronized to the telemetric system (Ninox Video Capture 125), to confirm the quality of each exercise. Horses had to perform between six and 15 consecutive and consistent strides for each exercise to be deemed a quality repetition. A minimum of five quality repetitions of each exercise were recorded. All horses had complete data for all multifidus locations. However, the T12 electrodes had to be removed before equipping the training device, resulting in comparisons only at T18 and L5 for the resistance device.

Exercise Data Processing

Motion artifact and noise from raw EMG signals was removed with a high-pass filter set at 40 Hz. Whole signals were then rectified. Lastly, a low pass filter was implemented with a 15 Hz cut off frequency. Using enveloped data, the onset and offset of muscle electrical activity within each of the five three-stride sections was labeled using Visual3D. Each of these activations were exported from Visual3D from the rectified and enveloped signals. The average rectified value and the maximum enveloped value were normalized to the maximal reference voluntary contraction, represented by the maximum EMG outcome measure observed across all trot strides for each horse, as previously described (25, 26). The average rectified signal (ARV) during the activation was used as an indication of average "work-done" by the muscle (27, 28). The peak value (PE) observed from the enveloped data represented the highest level of activation (27, 28) (**Figure 2**).

Statistical Analysis

Statistical analysis of the data was performed using SPSS Version 27. The statistical analysis of the EMG measures included all observations across the two factors; with and without the training device and with and without ground poles. A two-factor univariate analysis of variance was used to test for differences between the two factors across all observations. Any interactions between the factors were further explored with unpaired *t*-tests.

RESULTS

Horses

One gelding and three mares aged 4 to 14 years of various breeds from the University of Tennessee Veterinary Research and Teaching herd were utilized. All horses were deemed to be a grade 2 or less baseline lameness in any limb based on the American Association of Equine Practitioners lameness scale. All horses received oral phenylbutazone at a dose of 2.2 mg/kg twice daily started at least 24 h before data collection. All horses were visually sound during data collection as deemed by two experienced lameness veterinarians.

Gait Cycle Validation

The left longissimus muscle was determined to have two isolated peaks of activation per single trotting gait cycle. The first peak was associated with left front toe off, and the second peak was associated with left hind toe off, consistent with previously reported work (22). Using the data collected from the left longissimus muscle, the timing of three complete gait cycles was determined and extrapolated to the synchronized signal of the sensors implanted within multifidus muscle. Five three-stride segments were isolated from the data sets previously confirmed to be a quality repetition based on the video recording.

Fine-Wire Electromyography

Right and left T12 locations showed significant increases in bothARV and PE when horses were trotted over ground poles versus without ($p < 0.001$; **Table 1**).

When considering the multifidus locations tested both with and without the training device and with and without ground poles, significant interactions were seen between the two in all but the PE for left and right L5. The PE for both right ($p < 0.011$) and left ($p < 0.001$) L5 was significantly greater in horses trotting

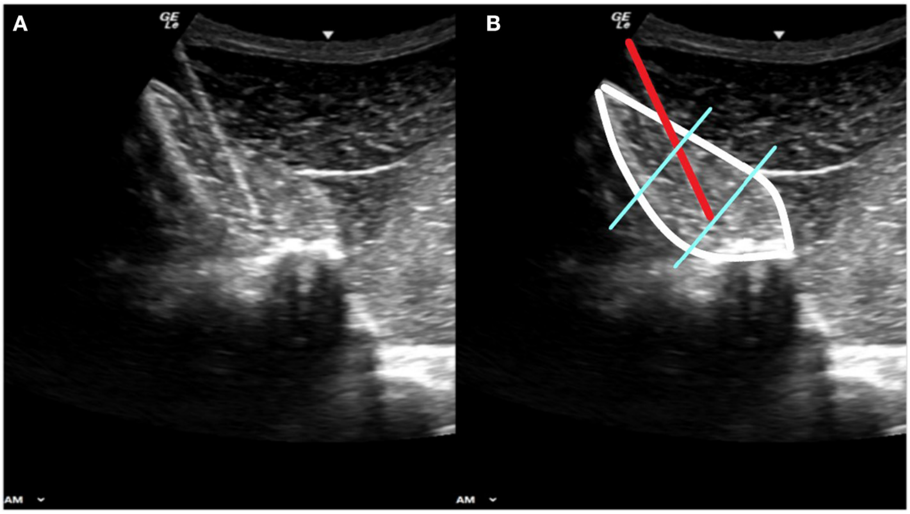

FIGURE 1 | Panels **(A)** and **(B)** show the same diagnostic ultrasound image. Panel **(B)** shows the outline of the multifidus muscle (white border) the 23 gauge needle carrying the fine wire electrodes (red line) with the electrode ends embedded at the junction of the middle and deep thirds of the muscle belly (blue lines).

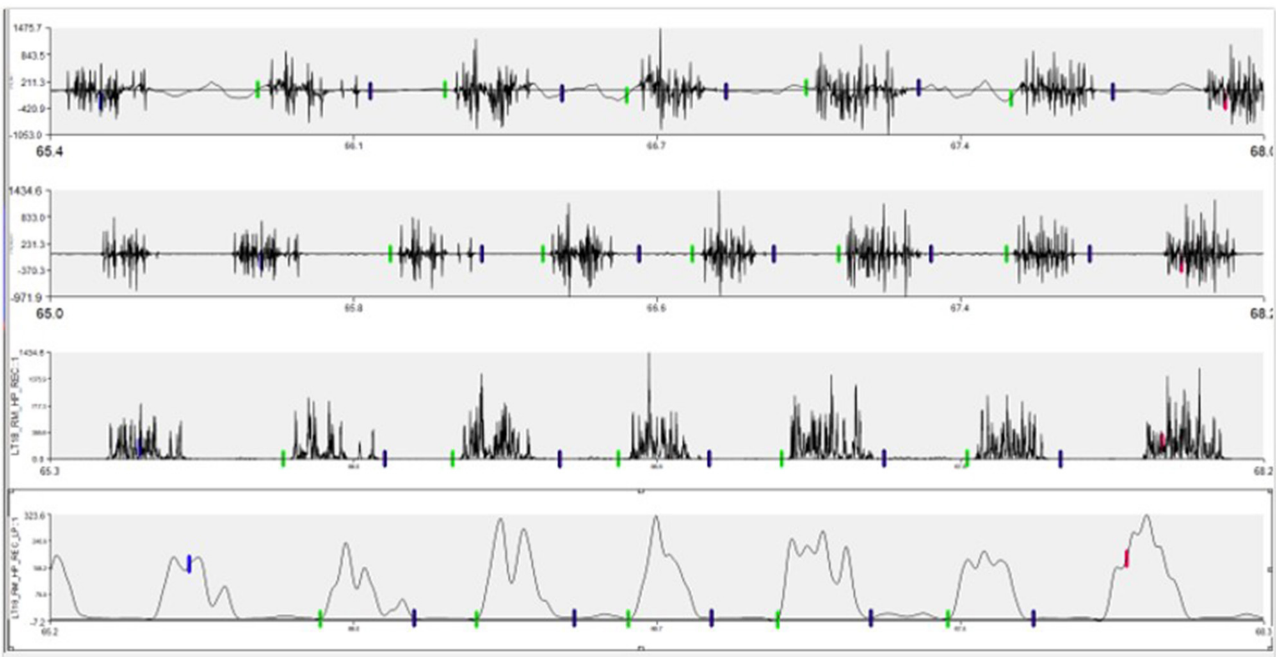

FIGURE 2 | Example of EMG signal changes through processing process. Top row is the raw signal as collected. Second row contains the signal after a high pass filter of 40 Hz was applied. The third row represents rectification. The bottom row is the final enveloped signal after the 15 Hz low pass filter.

over poles vs. no poles, but there was no significant change in PE in either location due to the training device (**Table 1**).

For the locations that showed significant interactions between the conditions, *post hoc* unpaired t-tests, were used to compare with and without the training device in the with and without ground poles conditions separately.

When the influence of the training device was investigated without ground poles, left T18 ARV ($p = 0.002$) and PE ($p < 0.001$) and right L5 ARV ($p < 0.001$) were significantly lower when using the training device, as compared to without the training device (**Table 2**).

When the training device was combined with trotting over ground poles, both left T18 PE ($p < 0.001$) and ARV ($p < 0.001$) and right T18 PE ($p < 0.001$) and ARV ($p < 0.009$) were significantly lower when the device was used. There was

TABLE 1 | Means (standard deviation) and comparisons of normalized EMG outcome measures for all conditions.

		Mean (SD)				**Poles vs. no poles**		**Training device vs. no training device**		
Muscle	**Outcome measure**	**No poles, no training device**	**Poles, no training device**	**Training device, no poles**	**Training device, poles**	**Mean difference (± 95% CI)**	***p*-Value**	**Mean difference (± 95% CI)**	***p*-Value**	**Interaction**
Left T12	Average rectified	0.4434 (0.23556)	0.6179 (0.26349)	n/a	n/a	0.175	<0.001Ŧ			
	Peak envelope	0.5057 (0.26889)	0.7236 (.26351)	n/a	n/a	0.218	<0.001Ŧ			
Left T18	Average rectified	0.4391 (0.28076)	0.5281 (0.30866)	0.3472 (0.17994)	0.2728 (0.16772)	0.007	0.756	−0.174	<0.001	<0.001*
	Peak envelope	0.5224 (0.32428)	0.6031 (0.33821)	0.4016 (0.20246)	0.3521 (0.18241)	0.016	0.556	−0.186	<0.001	0.014*
Left L5	Average rectified	0.2715 (0.26597)	0.4090 (0.27310)	0.3710 (0.22303)	0.4334 (0.25320)	0.1	<0.001	0.062	<0.001	0.005*
	Peak envelope	0.2308 (0.26436)	0.3821 (0.32181)	0.2897 (0.15635)	0.3657 (0.23664)	0.114	<0.001Ŧ	0.021	0.373	0.114
Right T12	Average rectified	0.5869 (0.40726)	0.8426 (0.28228)	n/a	n/a	0.256	<0.001Ŧ			
	Peak envelope	0.6567 (0.43235)	0.9611 (0.35881)	n/a	n/a	0.304	<0.001Ŧ			
Right T18	Average rectified	0.3049 (0.23703)	0.3866 (0.32605)	0.2687 (0.19079)	0.2618 (0.15112)	0.037	0.09	−0.081	<0.001	0.045*
	Peak envelope	0.3775 (0.26039)	0.4403 (0.35443)	0.3421 (0.22136)	0.3344 (0.19004)	0.028	0.264	−0.071	0.004	0.004*
Right L5	Average rectified	0.1833 (0.15608)	0.2347 (0.19312)	0.1670 (0.11342)	0.2006 (0.15582)	0.042	0.004	−0.025	0.087	0.001*
	Peak envelope	0.1489 (0.12945)	0.1801 (0.14016)	0.1441 (0.09891)	0.1789 (0.18250)	0.033	0.011Ŧ	−0.003	0.817	0.887

Significant interaction, conclusions were based on further post-hoc testing.
ŦSignificance ($p < 0.05$).

no significant difference between with and without the device in either left or right L5 ARV (**Table 3**).

The clinical importance of muscle activation for each exercise and location were also calculated as a percentage of change as compared to the baseline condition of trotting over flat ground (**Table 4**). Ground poles cause a general increase in both PE and ARV at all locations. The highest magnitude of change was seen in both T12 locations with increases of approximately 40%—50% in both ARV and PE. Left L5 exhibited increases in ARV and PE of 51 and 66% respectively. Left and right T18, and right L5 showed increases of 15%—30%. The training device caused decreases in both ARV and PE in all locations except left L5. Of note were decreases of 21 and 23% in ARV and PE respectively at left T18. When the training device and ground poles were used in combination, larger decreases in ARV and PE were observed at left and right T18 locations. Left and right L5 both showed effects similar to that was seen with ground poles alone (**Table 4**).

DISCUSSION

The multifidus muscle has garnered much attention in the equine literature due to implied associations of atrophy with axial spine disease (9) like what is reported in humans (29–34). Rehabilitation methods have focused on promoting hypertrophy of this structure (24, 35) however, muscle activity has never been directly measured. The work presented here is the first to document the overall muscle work and peak activity of the multifidus muscle in relation to specific therapeutic exercises and training devices.

Other back and hind limb muscles have been successfully investigated in the horse using electromyography (21–23, 25, 36–39). The longissimus dorsi muscle is noted to produce two bursts of activity for each trot stride with the main function of the longissimus dorsi suspected to provide overall spinal stiffness specifically in the sagittal plane (22, 38). The multifidus

TABLE 2 | *Post hoc* evaluation of training device without ground poles.

Muscle	Outcome measure	No training device Mean (SD)	Training device Mean (SD)	*p*-Value for equality of means (2-tailed)	Mean difference	95% CI (lower)	95% CI (upper)
Left T18	Average rectified	0.4647 (0.31870)	0.3472 (0.17994)	0.002Ŧ	0.11745	0.04516	0.18975
	Peak envelope	0.5717 (0.38510)	0.4016 (0.20246)	<0.001Ŧ	0.1701	0.08413	0.25607
Left L5	Average rectified	0.3608 (0.28953)	0.3710 (0.22303)	0.78	– 0.0102	– 0.08227	0.06187
Right T18	Average rectified	0.2940 (0.26092)	0.2687 (0.19079)	0.435	0.02528	– 0.0385	0.08906
	Peak envelope	0.3887 (0.29459)	0.3421 (0.22136)	0.208	0.04658	– 0.02612	0.11929
Right L5	Average rectified	0.2435 (0.15558)	0.1670 (0.11342)	<0.001Ŧ	0.07647	0.03848	0.11446

Ŧ*Significance ($p < 0.05$).*

TABLE 3 | *Post hoc* evaluation of training device with ground poles.

Muscle	Outcome measure	No training device mean (SD)	Training device mean (SD)	*p*-Value for equality of means (2-tailed)	Mean difference	95% CI (lower)	95% CI (upper)
Left T18	Average rectified	0.5281 (0.30866)	0.2728 (0.16772)	<0.001Ŧ	0.25529	0.18589	0.32469
	Peak envelope	0.6031 (0.33821)	0.3521 (0.18241)	<0.001Ŧ	0.25098	0.17506	0.32689
Left L5	Average rectified	0.4090 (0.27310)	0.4334 (0.25320)	0.514	– 0.02434	– 0.09778	0.0491
Right T18	Average rectified	0.3866 (0.32605)	0.2618 (0.15112)	<0.001Ŧ	0.1248	0.05375	0.19585
	Peak envelope	0.4403 (0.35443)	0.3344 (0.19004)	0.009Ŧ	0.10588	0.02642	0.18533
Right L5	Average rectified	0.2347 (0.19312)	0.2006 (0.15582)	0.171	0.03408	– 0.01487	0.08302

Ŧ*Significance ($p < 0.05$).*

muscle is speculated to have a similar function, however the fasiculated anatomy indicate it may be more suited to provide minute and rapid intersegmental stabilization. The activity of the multifidus has yet to be related to spinal motion in horses. The longissimus dorsi activation pattern has been noted to be increasingly variable in lame horses (36). It is unknown if the multifidus is similarly affected by the asymmetric motion associated with hind limb lameness.

We hypothesized that having horses trot over poles would increase the average muscle activation and peak activity of the multifidus as compared to trotting over the same surface without poles. This work supported that hypothesis in that both cranial thoracic regions showed significant increases in ARV and PE. Additionally, trotting over ground poles induced significantly more PE in left and right L5. Ground poles increased the ARV by 20%−51% in comparison to trotting over the same surface without poles in all locations. Similarly, the PE increased by 15%−66% across all multifidi locations measured.

We also hypothesized that when horses exercised wearing a resistance band-based training device the average and peak muscle activity would increase. Our findings did not support this hypothesis and actually resulted in significantly less ARV and PE in several locations. Other locations showed no significant change in ARV or PE when the device was

TABLE 4 | Percent change in outcome measure means for each exercise condition in comparison to baseline.

Muscle	Outcome measure	No poles, no training device mean (baseline)	Poles no training device mean	% changeŦ	No poles training device mean	% changeŦ	Poles and training device mean	% changeŦ
Left T12	Average rectified	0.4434	0.6179	39%				
	Peak envelope	0.5057	0.7236	43%				
Left T18	Average rectified	0.4391	0.5281	20%	0.3472	−21%	0.2728	−38%
	Peak envelope	0.5224	0.6031	15%	0.4016	−23%	0.3521	−33%
Left L5	Average rectified	0.2715	0.409	51%	0.371	37%	0.4334	60%
	Peak envelope	0.2308	0.3821	66%	0.2897	26%	0.3657	58%
Right T12	Average rectified	0.5869	0.8426	44%				
	Peak envelope	0.6567	0.9611	46%				
Right T18	Average rectified	0.3049	0.3866	27%	0.2687	−12%	0.2618	−14%
	Peak envelope	0.3775	0.4403	17%	0.3421	−9%	0.3344	−11%
Right L5	Average rectified	0.1833	0.2347	28%	0.167	−9%	0.2006	9%
	Peak envelope	0.1489	0.1801	21%	0.1441	−3%	0.1789	20%

Ŧ*Positive value indicates an increase in mean muscle activity of that condition as compared to the baseline condition of trotting without either the ground poles or training device. A negative value indicates a decrease in mean muscle activity.*

used as compared to without it. Interestingly, the mean of each outcome parameter and muscle location except the ARV of left L5 was lower when the training device was used as compared to the same conditions without it. With a larger sample size, more locations may have reached statistical significance.

When the clinical effects were calculated based on a percentage of the baseline condition, each of the T18 locations showed the largest decrease in muscle activation when ground poles were used in conjunction with the training device. The L5 locations each had results lower, but more similar to that of horses trotting over ground poles without the device. Therefore, the use of both ground poles and the training device promoted further decrease in activity in the caudal thoracic regions, and maintained a similar muscle output as if the device was not used in the lumbar areas.

The overall decrease in average and peak muscle activity seen with the use of the training device was surprising. Clinically, horses do seem to engage their back and hindquarters when the device is used. Pfau et al. found that horses who were exercised in the training device had decreased roll, pitch, and mediolateral displacement of the thoracolumbar region (8). They concluded the resistance band training device increased dynamic stability. However, our work implies that the decrease in motion is not due to increased multifidus activity. It is possible that the use of the training device activates other spinal stabilizers or abdominal or hind limb muscles. Similar studies have investigated the effects of a training device on the longissimus dorsi muscle, the main contributor of the epaxial muscle group in horses (21). They discovered that the training device also significantly decreased the muscle activity (8). Similar reductions in longissimus dorsi activity have been seen with the resistance band training device (25). The training device may alter the timing of activation and while the overall muscle work or peak activation were unchanged, the muscle may be active during a different phase of stride, providing more stability during motion. To more precisely determine the function of the multifidus muscle during motion, more advanced motion analysis should be performed in conjunction with multifidus EMG recording. Additionally, the training device may require a more prolonged training regimen to change muscle activation.

Specific limitations of this work include the inability to make conclusions based on the timing of the multifidus muscle activation in reference to each phase of the stride. This was not a primary objective of this study, as we were interested in the overall muscle activity due to therapeutic interventions, not classifying the timing of contractions. As stated previously, the multifidus muscle has several fascicles of varying lengths (40, 41). We took exceptional care to implant each sensor at a similar location and depth. However, the fascicles are not distinguishable on ultrasound, and therefore, some electrodes may be in different fascicles than others. While the anatomy is well documented (40, 41), the function of each fascicle has not yet been determined. Hyytiainen et al. (42) has shown variation of muscle fiber types between fascicles in horses as well as breeds. Muscles have been documented to alter in fiber type, based on the forces and functions required (43). Thus, there could be variation in EMG activity between fascicles. This work incorporates the use of four horses. Given the strongly significant results in some locations, we felt a sample size of four was adequate to explore the immediate effects of the conditions tested. Additionally, using all observations resulted in a calculated power of 1 at each muscle location and outcome measure. However, more changes could become evident with more horses. Lastly, velocity could not be standardized between trials, however, horses were kept at their own natural pace for each exercise repetition and care was taken to prevent fatigue. This is similar to other methods used (25, 26, 39). Additionally, each horse was maneuvered by the same handler throughout the study period, thus limiting the effect of variation from different handlers.

In conclusion, ground poles should be incorporated into every reconditioning and exercise plan focused on activating the multifidus muscle. However, caution should be used in regards to the resistance band training device tested, as both average and peak muscle activation were significantly lower in several locations. Further work should be performed to investigate the effects of the training device on other spinal stabilizing epaxial musculature and in conjunction with motion analysis.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The animal study was reviewed and approved by University of Tennessee Institutional Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

TU performed all data collection, processing, and main manuscript preparation. KS assisted with data collection and manuscript editing. DL and JR assisted with study design, statistical analysis, data processing, and manuscript editing. HA assisted with study design, and manuscript editing. All authors contributed to the article and approved the submitted version.

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Intra-Articular Injections of Allogeneic Mesenchymal Stromal Cells vs. High Molecular Weight Hyaluronic Acid in Dogs With Osteoarthritis: Exploratory Data From a Double-Blind, Randomized, Prospective Clinical Trial

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This double-blind, randomized, prospective clinical trial was conducted to obtain exploratory data comparing the efficacy of intra-articular allogeneic mesenchymal stem/stromal cells (MSC) to high molecular weight hyaluronic acid (HA) for the treatment of pain associated with canine osteoarthritis (OA). Objective gait analysis (%Body Weight Distribution, %BWD), accelerometry, clinical metrology instruments and veterinary exams were used as outcome measures during various time points throughout the 48-week study period. Fourteen dogs with elbow or coxofemoral OA were enrolled and assigned in a 2:1 ratio to the treatment groups. Each patient received a set of two injections 4 weeks apart. Self-limiting joint flare was observed in seven patients, with six of these in the MSC group. Ten patients completed all follow-up appointments. Both treatment groups showed evidence of mild improvement following the treatment, but the results were inconsistent among the various outcome measures assessed. Overall, dogs enrolled in the HA group showed greater improvement compared to the MSC group. The primary outcome measure, %BWD, showed evidence of improvement, when compared to baseline values, at 36 weeks after injection for the HA group only ($p = 0.048$, estimated difference: 4.7). Similarly, when treatment groups were compared, evidence of a difference between treatment groups (with the HA-group showing greater improvement) were identified for weeks 24 and 36 ($p = 0.02$ and 0.01, respectively). The small sample size of this exploratory study does not allow firm conclusions. However, until studies with larger sample sizes are available, the current literature combined with our data do not support the clinical use of intra-articular MSC therapy over high molecular weight HA for the treatment of canine OA at this time.

Keywords: osteoarthritis, dog, stem cell therapeutics, hyaluronic acid, regenerative medicine

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INTRODUCTION

Osteoarthritis (OA) is the most common human joint disorder in the world, estimated to clinically impact ∼30 million adults in the US (1). Based on an unpublished survey of 200 veterinarians performed in 1996, it is frequently stated that at least 20% of dogs over 1 year of age are affected (2). In a recent publication, Wright et al. reported an even higher prevalence of 38% in a study population of 500 dogs. These dogs were not previously diagnosed with OA, did not receive medications for treatment of OA, and presented for routine care (3). On the other hand, review of a large veterinary database from primary care facilities in the UK described the overall 1-year period prevalence of OA to be 2.3–2.5%, with certain breeds showing a higher prevalence (e.g., Golden Retriever, 7.4%; Labrador, 6.1%) (4, 5). However, the latter numbers likely heavily underestimate the true prevalence since they are based on retrospective medical record data review only (6).

Regardless of the true prevalence of OA, because of its progressive and debilitating nature, OA poses a significant welfare issue to canines and humans alike. In a recent epidemiologic study investigating more than 12,000 German Shepherd Dogs in the UK, osteoarthritis/musculoskeletal disease was the most common cause of death; surpassing even neoplasia (7). Yet, there still is a lack of treatment options that consistently offer pain relief and improve quality of life without the risk of substantial adverse effects. Currently, there are multiple treatment options to address the pain associated with OA ranging from surgery (e.g., arthroscopy, joint replacement) to a myriad of medical management interventions (e.g., weight loss, anti-inflammatories, analgesics, nutritional supplements, physical rehabilitation, acupuncture, shockwave therapy, etc.). A multi-modal approach is often pursued to enhance treatment efficacy while attempting to minimize systemic adverse effects (8). Targeted local therapy, such as intra-articular injections, has been a developing area of interest. Several intra-articular treatments have been reported in veterinary medicine, the most common being corticosteroids, hyaluronic acid (HA), platelet-rich plasma (PRP), and mesenchymal stem/stromal cells (MSC) (9, 10).

Viscosupplementation of joints has been used for decades in animal and humans (11). Hyaluronic acid, a naturally occurring non-sulfated glycosaminoglycan with excellent viscoelastic properties, is crucial for normal joint function. Because of its ability to trap water, it aids in providing compressive strength to articular cartilage, thereby acting as a natural shock absorber. The benefits of intra-articular injection of HA include anti-inflammatory, analgesic, and chondroprotective effects. HA can be produced either by extraction from animal tissues (e.g., chicken combs) or *in vitro* by bacterial fermentation. Independent of the production method, it can be stored at room temperature and is readily available off-the-shelf (12). Many studies have shown that HA can be beneficial in patients with OA, however, the magnitude of improvement is generally accepted to be small and may depend upon the molecular weight of the product (11–14).

Regenerative medicine has recently gained popularity in the treatment of OA. Intra-articular therapy with MSCs is purported to alleviate OA pain *via* several pathways (15). Intra-articular MSCs are theorized to stimulate a release of chemical mediators that improve the secretion of growth factors, which enhance cartilage repair and regeneration through processes such as cell migration, proliferation, differentiation, and matrix synthesis, though the exact mechanism remains to be elucidated (16). Additionally, MSCs have immunomodulatory properties that can attenuate the immune responses in the host by inhibiting activation of T and B lymphocytes and natural killer cells, which are known to play a role in the development and progression of OA (17).

MSC are obtained from various sources (e.g., bone marrow, placenta, umbilical cord, etc.), but adipose-derived MSC have the particular advantage of being both abundant and a more easily harvested resource (18). Both autologous and allogeneic adipose-derived MSC have been used in veterinary medicine, though to date, there is no consensus on which is safer and more effective (19). Treatment with autologous adipose-derived MSC decreases risk of infectious disease transfer and immunogenicity issues but has some inherent morbidity associated with harvesting tissue; studies in mice have found that the number and quality of cells decrease with age of the donor (20), which may limit application in patients suffering from OA as many are in the middle to older age group. While there are some disadvantages to the use of allogeneic adipose-derived MSC such as potential infectious disease transfer and overexpansion (to attain large stocks of cells), their use has the benefit of using healthy, young donors to maximize cell quantity and quality, and eliminating any morbidity associated with the harvesting procedure for the patient that is receiving the MSC treatment (21).

Several studies have evaluated the efficacy of MSC for treatment of canine OA with promising results in the last decade (9, 22). Nevertheless, studies have not confirmed whether the effects of MSC are superior and/or safer than other existing intra-articular treatment options (23, 24). To date, there is a lack of conclusive data comparing intra-articular MSC treatment with readily available, off-the-shelf treatments such as hyaluronic acid (HA). The purpose of this study was to collect exploratory data comparing the efficacy of intra-articular allogeneic MSC (Allo-MSC) to HA for the treatment of pain associated with canine OA. We hypothesized that the Allo-MSC treatment group would demonstrate improved outcome (based on the primary outcome measure, %Body Weight Distribution [%BWD]) compared to the HA treatment group.

MATERIALS AND METHODS

Patient Selection and Study Protocol

The ARRIVE 2.0 guidelines [Reporting of Animal Research: Reporting of *in vivo* Experiments (25)] were followed in designing and reporting of this research. The trial was a double-blind, randomized, prospective clinical study which recruited dogs with lameness attributable to naturally occurring OA of the coxofemoral or elbow joint. The study was approved by the institutional review board (Clinical Review Board #2017-129), and owner consent was obtained for each case. Given the exploratory nature of this study, no sample size calculation was performed. Client owned dogs presented to Colorado State University were evaluated by a board-certified orthopedic surgeon and overseeing trial veterinarian at the enrollment visit. Inclusion criteria were defined as follows: body weight over 10 kilograms, radiographic evidence of OA of the joint to be treated, and Canine Brief Pain Inventory (CBPI) values for pain severity score (PSS) and pain interference score (PIS) of $\geq$2 for each in their initial owner questionnaire. The patients were required to display a visually identifiable lameness on subjective gait analysis. Additionally, objective gait analysis was performed, and %BWD had to be outside of a previously reported reference range for the affected limb (26). Patients had to have consistent clinical signs that had been present for at least 4 weeks prior to enrollment. There were no age or breed restrictions. Only patients with a score of $\geq$3 based on a previously described (27) Subjective Orthopedic Scoring system (SOS) grading for combined scores of "Lameness at walk" and "Lameness at trot" were included. Lameness secondary to OA could be bilateral, but one side had to be worse based on both subjective (SOS grading) and objective (%BWD) measurements. Exclusion criteria included concurrent systemic diseases (e.g., Cushing's disease, diabetes mellitus, chronic liver, or kidney disease), patients unable to safely undergo sedation (e.g., cardiomyopathy), inconsistent OA management over the prior 4 weeks, and owners that were unable to follow the proposed recheck schedule and/or complete questionnaires as outlined in the study protocol over the 1-year study duration.

Outcome Measures

Various outcome measures were scheduled to be collected at weeks 0, 4, 8, 12, 24, 36, and 48 of the trial (see **Figure 1**). Objective gait analysis was performed using a pressure sensitive walkway (Tekscan HR Walkway^{TM} 6 VersaTek System), and %BWD, defined as {[PVF (N) of the limb/total PVF (N) of all four limbs in one gait cycle] × 100}, was collected as previously described (27). Briefly, animals were evaluated at the walk or trot (based on their preference), but the velocity was kept consistent between time points. For data analysis, trials from an individual dog were only considered for analysis if they fell within a velocity range $\leq$0.3 m/s between time points. The goal was to obtain trials with a consistent velocity, in a straight line, without lateralization of the head, pulling on the lead, or stepping off the PSW (three in each direction). The protocol was adjusted as needed with the goal of capturing at least one valid trial in either direction. If animals only tolerated walking in one direction, then only trials in that direction were acquired (i.e., aiming for six valid trials in one direction). The body weight and the number of trials required were recorded at each time point.

Accelerometers were used to objectively measure physical activity data. The patients had the accelerometer collars placed for minimum of 4 weeks before the first injection to obtain baseline activity level (i.e., week −4 to week 0). Total activity counts (AC) and activity intensity was collected as previously described using the Actical accelerometer (27, 28). Briefly, the epoch was set to 60 s, and only AC data with a minimum of 140 min of recorded activity per day was used for analysis. Data was recorded as the automatically generated number of minutes per week spent in the different activity categories assigned by the Actical device (28). Data was recorded continuously throughout the entire study. Accelerometry data was pre-processed to average the data over 4 weeks including the time point of interest (0, 12, 24, and 36 weeks), and analysis was performed the same as was performed on the raw data. Activity data was only analyzed for those time points where sufficient data was available.

Owner outcome assessment of pain and mobility at home was performed using validated questionnaires (CBPI and Client Specific Outcome Measures, CSOM). CSOM questions based on previously published information were divided into activity and behavior categories and scoring was performed as previously described (21). Briefly, the owners were asked to pick 5 time and place specific activities and grade them on a 1–5 scale (1 = no problem, 2 = a little problematic, 3 = quite problematic, 4 = severely problematic, and 5 = impossible) and pick 3 activities related to behavior, also graded on a 1–5 scale (1 = significantly less than normal, 2 = less than normal, 3 = normal amount, 4 = more than normal, and 5 = significantly more than normal). These questions were normalized for analysis with higher numbers indicating worsening of symptoms and lower numbers indicating improvement of symptoms. The CBPI questionnaire was used in unedited form as recommended by the developer of the questionnaire (29). The same owner was required to complete all questionnaires at each time point in a dependent interview process either in-person or over the phone due to pandemic-related restrictions of in-person visits.

Allo-MSC Preparation

MSCs were generated from adipose tissues collected from the inguinal region and/or abdomen of anesthetized, purpose-bred research hound dogs <4 years of age used in a veterinary teaching laboratory. Prior to use of adipose tissue samples dogs were tested for infectious diseases and routine laboratory testing was performed as previously described (30). The adipose tissues were collagenase-digested (collagenase 1 mg/ml Sigma-Aldrich St. Louis MO) for 30 min at 37°C then centrifuged at 1,050× g for 5 min, triturated, and then recentrifuged. The resulting stromal vascular fraction was plated for enrichment and expansion of MSC in low glucose Dulbecco's Modified Eagle medium with 5% essential and non-essential amino acids, glutamine and penicillin-streptomycin (Gibco, Thermofisher Scientific Waltham MA), and 15% heat-inactivated fetal bovine serum (VWR, Radnor PA). Cells were incubated at 37°C in 5% CO_2 and passaged when 80–95% confluent, harvested on the day of injection by detaching cells using 1% trypsin (Sigma-Aldrich, St. Louis MO), washed three times with Dulbeccos Phosphate Buffered Saline (DPBS;Sigma-Aldrich, St. Louis MO), and resuspended in 2 ml DPBS for injection. MSCs were used between passages 2–5, and cell count and viability assessments were performed by manual count using a hemocytometer and trypan blue dye to detect dead cells. Cell viability was required to be >95%, and the phenotype, morphology, and trilineage differentiation capacity of the MSCs was required to be consistent with that previously described for canine MSC (30). Prior to initiation of the study, cell lines to be utilized in this study were assessed for phenotypic markers

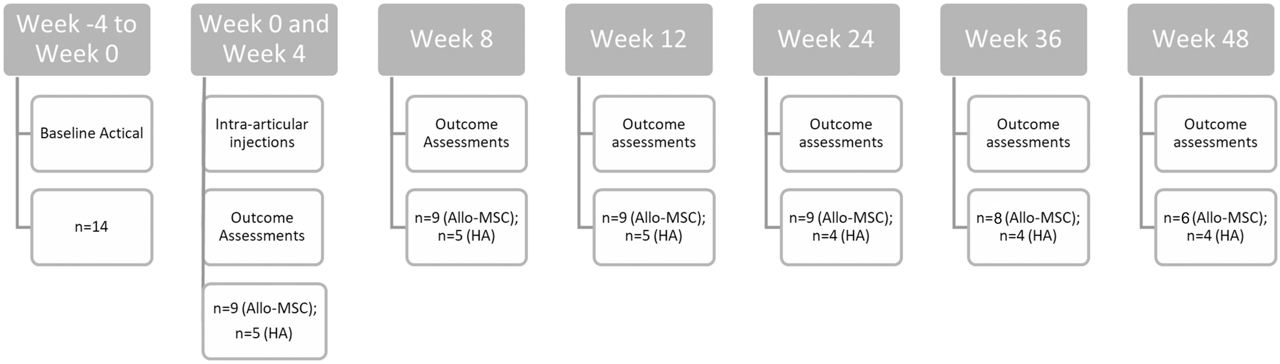

FIGURE 1 | Graphical representation of the study timeline and sample size.

associated with canine MSC (CD105, CD73, CD44, CD45, CD34) *via* flow cytometry. They were additionally examined for the ability to differentiate into chondrocytes, adipocytes, and osteocytes utilizing StemPro chondrogenesis, osteogenesis, and adipogenesis kits per manufacturer's instructions (Gibco, Thermofisher Scientific, Waltham MA). Prior to MSC injection an aliquot of cells was also aseptically collected and plated to verify that the cells were free of bacterial, mycoplasma or fungal contamination. Briefly, the cell suspension was cultured on sheep blood agar, MacConkey agar (BD, Franklin Lake NJ), mycoplasma agar (Udder Health, Bellingham WA) and Sabaroud Dextrose agar (BD, Franklin Lake NJ). Fungal cultures were incubated at room temperature for 30 days, mycoplasma cultures were incubated at 37°C with 5% CO_2 for 7 days, and blood agar and MacConkey plates were cultured at 37°C for 48 h after which cultures were considered negative. Prior to injection of the last two dogs with Allo-MSC, the cell culture protocol was altered to incubate the cells in serum free media for 48 h prior to injection using StemPro xeno free media (SFM; Gibco, Thermofisher Scientific, Waltham MA) because of the joint flare observed in two patients.

Intra-Articular Injection Administration

Dogs were randomly assigned to the Allo-MSC or HA group, in a 2:1 ratio, respectively. All clinicians involved in collecting outcome measurement data were blinded to the treatment administered by covering the injectate syringe with parafilm (and transferring the HA to a regular syringe). All dogs received intra-articular injections of either Allo-MSC (10×10^6 MSCs) or HA (SYNVISC-ONE, Genzyme, Ridgefield, New Jersey; produced from chicken combs with an average molecular weight 6,000,000 daltons for hylan A; 2 mls per joint for dogs >15 kg and 1 ml per joint for dogs <15 kg; 4.8 mg/ml,) at 2 time points 4 weeks apart (i.e., week 0 and 4). For administration of intra-articular injections, patients were sedated with Dexmedetomidine (5 mcg/kg IV) and Hydromorphone (0.05 mg/kg IV) and reversed with Atipamezole (50 mcg/kg IM) following the procedure. Vital parameters were monitored throughout sedation. The affected joint was clipped and prepped using standard aseptic technique. The elbow joint was identified using palpation of local landmarks to guide the injection; coxofemoral joints were injected using ultrasound guidance. To confirm injection into the joint, aspiration of joint fluid prior to administration (for elbow joints) or verification of distension of the joint capsule *via* ultrasound (for coxofemoral joints) was performed. For cases with bilateral lameness, clinical judgment was used to determine if injection of both joints was indicated (i.e., patients with bilateral lameness were allowed to receive treatment, with either HA or Allo-MSC, in both joints). Joint flare was defined as worsening of lameness within 48 h after intra-articular injection. To identify post-injection joint flare, owners were called ∼48 h after the injection to inquire whether their dog's lameness had worsened (i.e., joint flare), stayed the same or improved. If worsening of lameness persisted beyond a few days, owners were asked to return the patient for evaluation.

Statistical Analysis

Statistical analysis was completed using a commercially available software package (SAS 9.4 software, SAS Institute Inc., Cary, NC, USA). Summary statistics (mean, standard deviation, min, median, max) were calculated for each variable, treatment, and time point. Residual diagnostic plots were used to evaluate model assumptions of normality and equal variance. A mixed model was fit for each response variable separately. Specifically, treatment and time and treatment by time interaction were included as fixed effects. To account for repeated measures across time, dog was included in the model as a random effect. For each time point, comparisons were made between treatments. For each treatment, comparisons between downstream time points vs. baseline (Week 0) were performed using Dunnett's method. For Actical data specifically, 4 weeks of data preceding the time point of interest (i.e., weeks −4 to week 0 for week 0/baseline; weeks 8–12 for week 12; weeks 20–24 for week 24, and weeks 32–36 for week 36) were averaged and compared to baseline, using Dunnett's method as previously described. If a dog had a sedentary value <5,000, this entire week of data was omitted prior to averaging. If a dog had fewer than 3 weeks of observations contributing to the average, this observation was excluded. Actical "Vigorous" data was not used for formal analysis because most values were zero.

RESULTS

A total of 14 dogs were enrolled, consisting of 6 male castrated, 2 male intact, 5 female spayed, and 1 female intact dogs (**Table 1**). The mean age was 8.75 years (range 1.5–13 years); the mean body weight was 30.1 kg (range 11–45 kg). There were eight patients with elbow OA and six patients with coxofemoral OA. From the initial population of 14 patients enrolled, 10 patients (Allo-MSC:$n = 6$; HA:$n = 4$) completed all follow-up appointments over the 48-week period. Two patients were euthanized prior to completion for reasons unrelated to the study (at week 36 and 48, respectively). Another patient (in the HA group) was withdrawn at 12 weeks as the owner elected to go forward with a bilateral femoral head and neck ostectomy, and one was lost to follow-up for their final study visit.

The most commonly reported adverse event after intra-articular injection was self-limiting joint flare after the injection ($n = 7$, with 6/7 from the Allo-MSC treatment group; $n = 3$ elbow joints and $n = 3$ coxofemoral joints in the Allo-MSC treatment group and $n = 1$ elbow in the HA treatment group) that resolved either without treatment or with short-term anti-inflammatory medications and ice-packing. Two patients (one patient in the Allo-MSC treatment group and one patient in the HA treatment group) were noted to have self-limiting joint flare for the first 2 days following the injection, and then presented again 2–3 weeks later for acute worsening of lameness (toe-touching lameness of the affected limb without inciting cause). Aerobic and anaerobic synovial fluid culture and cytology performed for both patients did not show evidence of joint infection, however, antibiotic therapy (cephalexin for the patient in the Allo-MSC treatment group and amoxicillin trihydrate/clavulanate potassium for the patient in the HA treatment group) was instituted regardless. In both cases, culture and cytology was repeated after 6–8 weeks of antibiotic therapy. Both cases were maintained in the study for continued follow-up due to clinical improvement, and the lack of positive synovial fluid cultures and cytologic evidence of septic arthritis (i.e., inability to attribute the flare to iatrogenic septic arthritis).

Overall, both treatment groups showed evidence of mild improvement following the treatment, but the results were inconsistent among outcome measures assessed (see **Appendix** for details of all outcome measures and **Figure 2**). The primary outcome measure, %BWD of the most affected limb, showed evidence of improvement in the HA group when compared to baseline at 36 weeks ($p = 0.048$), while the Allo-MSC group did not exhibit any major degree of improvement when compared to baseline at subsequent post-treatment time point (**Table 2**). When treatment groups were compared, evidence of a difference between treatment groups were identified for weeks 24 and 36 ($p = 0.02$ and 0.01 respectively), with the HA group showing greater improvement.

The accelerometry data revealed consistently higher total activity levels in the Allo-MSC group (including baseline), but no difference was noted when compared to total activity levels in the HA group. Evidence of a decrease in the immediate post-injection treatment series time point (12 weeks) within the Allo-MSC group was noted compared to baseline with a decrease in the light ($p = 0.02$) and moderate ($p = 0.03$) activity counts and an increase in sedentary activity counts ($p = 0.01$).

Despite both groups showing a decrease in CSOM behavior questionnaires after completion of the treatment series, there was disparity noted between the two groups ($p = 0.04$), with the HA group showing a greater degree of improvement. Similarly, for comparisons between treatment groups, a difference between groups was evident at the 24-week time point for comparison of SOS ($p = 0.05$; with the HA group showing greater improvement). No evidence of difference between treatment groups or between time points within each group were identified for any other outcome measures.

DISCUSSION

Several recent studies have evaluated intra-articular injections with MSC in dogs with OA, many suggesting that there may be some benefit associated with this treatment (9, 22–24). However, most of these studies either lack appropriate outcome measures, lack a control group, or the control group consists of no treatment. While choosing no treatment as the control obviously increases the ability to detect differences between groups, comparison to HA is perhaps more clinically relevant. Given that the mechanism of action of HA is well-defined and the treatment is simple, safe, and comparably inexpensive, it serves as a logical clinical alternative comparison group. This is the first canine study comparing the clinical efficacy of repeated intra-articular injections of HA to Allo-MSC. While we expected improvement in the HA treatment group, we did not expect it to have comparable, if not better, treatment efficacy compared to the Allo-MSC treatment group.

Our study results revealed overall mild improvement following the two treatment injections in both groups but did not reveal one treatment to be superior to the other across multiple outcome measures. Owner questionnaires and SOS results were mildly improved in both groups with the HA group showing a greater degree of improvement in the CSOM questionnaire at week 12 and with SOS at week 24. It is important to note that both of these outcome measures are subject to the "caregiver placebo" effect (31). Particularly because there was no placebo arm, the caregivers (veterinarians for SOS and owners for CBPI and CSOM scoring) are likely to report a benefit for both treatments. As such, objective outcome measures are most relevant for this particular study design when it comes to determining overall efficacy of the treatment rather than comparison of the two treatments. For objective outcomes measures, the HA group demonstrated greater improvement in %BWD (an outcome measure unaffected by caregiver placebo effect) compared to the Allo-MSC group at the 24 and 36 week time points. The accelerometry data showed no evidence of sustained increase in activity post treatment for either group.

There are many reasons that may explain the findings of the present study, including the potential superiority of the high molecular weight (HMW) HA used, potential inferiority of the Allo-MSC used (compared to MSC types used in previous studies), the study design, and/or the utilized outcome measures.

TABLE 1 | Overview of the study participants.

Breed	Group	Sex	Age (years)	Weight (kg)	Site of injection	Study endpoint
Entlebucher mountain dog	ALLO-MSC	MC	10	25.3	Right elbow	Euthanized
Mixed breed dog	HA	FS	13	23.3	Right elbow	Completed
Chesapeake bay retriever	ALLO-MSC	FS	8	27.7	Left hip	Completed
Labrador Retriever	ALLO-MSC	FS	10	40.5	Both hips	Completed
Labrador retriever	HA	MC	8	31.6	Right elbow	Completed
Border collie mix	HA	FS	6	18.1	Both hips	Surgical treatment pursued
German shepherd dog	ALLO-MSC	MC	10	45	Right elbow	Completed
Siberian husky	ALLO-MSC	FI	3	21.4	Right hip	Completed
Golden retriever	ALLO-MSC	MC	12	34	Left elbow	Euthanized
German shepherd dog	HA	MI	1.5	39.4	Left elbow	Completed
Labrador retriever	ALLO-MSC	MC	10	37	Left elbow	Completed
Labrador retriever	ALLO-MSC	MI	12	33.5	Left hip	Completed
Labrador retriever	ALLO-MSC	FS	8	34.3	Right hip	Lost to follow-up
West highland terrier	HA	MC	11	11	Right elbow	Completed

MC, male castrated; FS, female spayed.

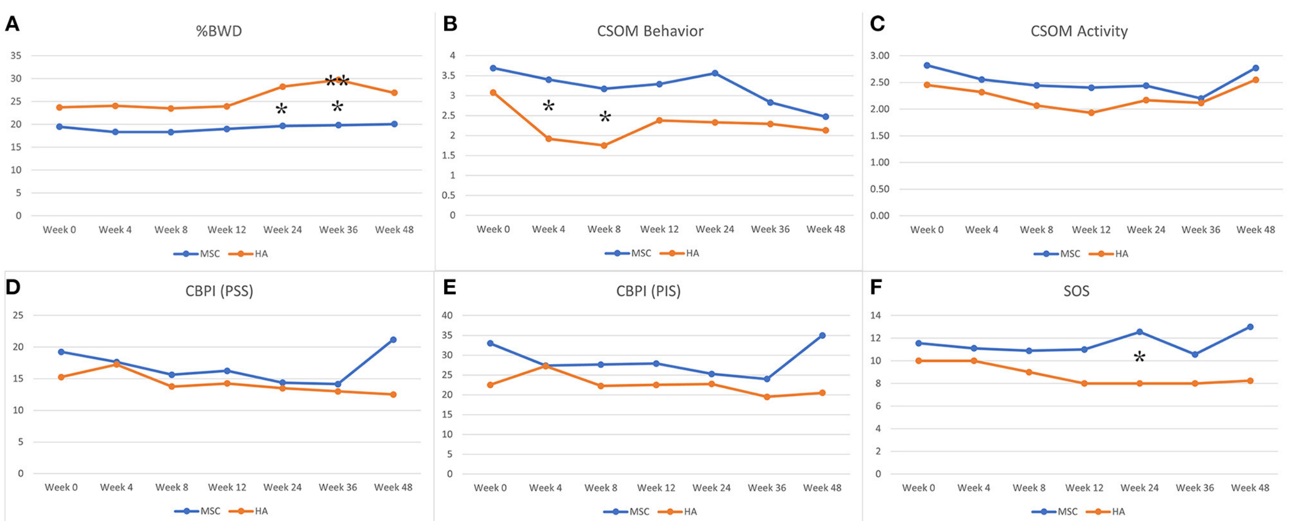

FIGURE 2 | Graphical representation of data for both groups for %Body Weight Distribution (%BWD), Client Specific Outcome Measures (CSOM), Canine Brief Pain Inventory (CBPI) (PSS = pain severity score and PIS = pain interference score), and Subjective Orthopedic Scoring system (SOS). *Indicates evidence of a difference for comparison between the mean values for the two treatment groups. **Indicates evidence of a difference for comparison of mean baseline value to the subsequent time point within the treatment group. **(A)** %BWD, **(B)** CSOM behavior, **(C)** CSOM activity, **(D)** CBPI (PSS), **(E)** CBPI (PIS), and **(F)** SOS.

TABLE 2 | Comparison between the mean values (±SD) of the primary outcome measure (%BWD of the affected limb) for the two treatment groups at each time point.

Group	Week 0	Week 4	Week 8	Week 12	Week 24	Week 36	Week 48
ALLO-MSC	19.48 (4.58)	18.33 (3.99)	18.3 (4.89)	19 (5.42)	19.67 (4.79)[a]	19.84 (6.84)[b]	20.07 (6.17)
n=	*9*	*9*	*9*	*9*	*9*	*8*	*6*
HA	23.72 (6.27)	24.05 (5.98)	23.5 (6.07)	23.96 (4.48)	28.25 (4.12)[a]	29.73 (4.58)[b*]	26.9 (4.36)
n=	*5*	*5*	*5*	*5*	*4*	*4*	*4*

[a,b]Values with the same superscript indicate evidence of difference ($p < 0.05$) between the mean values for the two treatment groups at the respective time point.
**Values with an asterisk indicate evidence of difference ($p < 0.05$) for the comparison of mean baseline values to the respective time point within the treatment group.*

For example, while accelerometers have been evaluated in several research studies, there are some concerns regarding the ability of this data to identify differences in activity patterns due to the number of variables [e.g., owner-induced activity, data collection and processing, accuracy of the devices, and averaging of data resulting in the inability to detect short-term changes such as changes in sleep and activity patterns (32)]. While OGA is a well-accepted outcome measure, and %BWD has been described as the most accurate outcome measure when using PSW in a heterogenous study population (33), there many factors that influence OGA data (34). Furthermore, it only captures single, brief time points, which is why a set of diverse outcome measures should be considered in clinical trials (28).

Previous studies using HA in humans and canines with OA reported several beneficial effects including anti-inflammatory, analgesic, and chondroprotective properties (11, 12). We chose to use HA as a comparison group because HA is readily available to clinicians when considering intra-articular injections. Alternatively, we could have chosen PRP or saline for our control group. We did not opt for PRP because there is still substantial controversy regarding the ideal treatment regime and constitution of PRP, making it difficult to compare studies using different types of PRP. We did not choose saline injections because it is not a clinically applied treatment and therefore a superiority of MSC over saline would not be as clinically relevant. The molecular weight of native HA has been reported to be ∼4,000–10,000 kilo Daltons (kDa) in humans, and 2,000–3,000 kDa in horses (12). While there is no clear definition of high vs. low molecular weight, products with a molecular weight of <1,500 kDa are frequently considered LMW while products with a molecular weight >5,000 kDa are frequently considered HMW. We chose HMW HA for this study based on several studies suggesting a superiority to LMW HA (12). There has been some controversy over the efficacy of HA for the treatment of knee OA in humans, with some authorities suggesting that treatment does not result in a clinically relevant difference. A recent study, however, found that these results may be due to the consolidation of different molecular weights of HA in meta-analyses with HMW HA resulting in a clinically relevant benefit (14). Cook et al. compared the efficacy and safety of LMW and cross-linked HMW HA intra-articular injections in surgically induced stifle OA in dogs, using saline injections as a control. Their findings suggested that overall, treatment with HA showed more improvements in pain, function, and range of motion compared to the saline control, but the HMW HA treatment group demonstrated the most improvements (35). Alves et al. described reduction in pain and functional improvements when evaluating the effect of a single intra-articular injection of HMW HA in canines with naturally occurring hip OA (36). Our preliminary results are in line with these previous reports regarding efficacy of HMW HA.

Unfortunately, MSC treatment is not standardized, and many variables exist that may have substantial impact on the outcome, including but not limited to the source and number of cells, culture expansion methods, media components, cryopreservation, and administration frequency. The present study utilized culture-expanded, adipose-derived Allo-MSC. It is possible that the cells used in the present study provide inferior benefits compared to MSC used in other studies. However, the cells used in this study displayed phenotypic and functional characteristics consistent with commonly accepted definitions of MSCs which were similar to descriptions in other published studies using canine Allo-MSC (9, 21, 37). Allogeneic cells have been reported to be safe and have several key advantages over autologous cells and have been used to safely treat canine patients with OA (9, 21, 37). Some of the most attractive advantages of Allo-MSC include the ability to expand and bank Allo-MSC, and the ability to establish cells lines that may produce more uniform cellular therapy to allow for more predictable response (19). Other advantages include the elimination of a separate cell collection procedure and the ability to source cells from younger, healthy donors. While there is potential to develop Allo-MSC as another "off-the-shelf" therapy that may benefit a larger scale of veterinary patients, further research into the safety and efficacy of the treatment must be pursued prior to the widespread commercialization efforts.

In this study, seven patients experienced some degree of joint flare, and six out of seven of those patients were in the Allo-MSC group. This is similar to findings reported in other studies involving intra-articular injections, particularly repeat injections of Allo-MSC (18, 38). Of the six joint flares in the Allo-MSC group, two were reported to have flare after both injections, two had flare only after the first injection, and another two had flare only after the second injection. Joswig et al. suggested that the xeno-contaminants used to produce Allo-MSC, such as Fetal Bovine Serum (FBS), may cause development of recipient antibodies to the foreign bovine proteins with subsequent rejection of cellular therapy in equine models. This may result in the joint flare observed in patients, typically reported after repeated intra-articular injections of Allo-MSC (39). In this scenario, one would expect that joint flare would be worse on repeated injections due to sensitization either to foreign MHC molecules or to sensitization against FBS proteins, unless the animal had been previously exposed. The reports of joint flares appear to be distributed inconsistently with this theory in our study, although previous exposure was not definitively ruled out. Further investigation comparing the various preparation methods, including the use of serum free media, as well as the cause of potential inefficacy and joint flare are required before appropriate clinical recommendations can be made.

One of the obvious limitations of the present study is inherent to the small sample size associated with the exploratory nature of this clinical trial. While there are many published studies with small sample sizes in veterinary medicine, it is important to understand their limitations. Specifically, the possibility of identifying a statistically significant difference that does not reflect a true effect, thereby producing misleading results (40). While the term "Pilot Study" is frequently used in veterinary medicine, Rishniw et al. (41) suggested that this term most frequently represents a "deficiency signal" to editors, indicating an underpowered study. We therefore describe the current study as an "Exploratory Study," indicating that the purpose of this study is not to provide conclusive results, but rather to generate exploratory data that can be used to determine future hypotheses and study designs. Based on the results of the presented data, one future research hypothesis may be that both HA and Allo-MSC provide mild benefit for the treatment of canine OA, yet that there is no difference between the two products. Besides the small sample size, there are several other study weaknesses that should be considered for future research aiming to answer this potential hypothesis. Examples include the heterogenous study population, inclusion of animals with both elbow and hip OA, absence of biomarker evaluation, and lack of a control group. Additionally, due to missing data points, the sample sizes varied across response variables and time points. The inconsistency in between outcome measures illustrates that more robust studies are required. Therefore, our findings should not be over interpreted and be limited to guide future research rather than draw firm conclusions regarding the efficacy of the products tested. Larger controlled trials are clearly needed to confirm or deny the preliminary findings from the present study.

Overall, the current literature provides insufficient evidence to justify intra-articular MSC injections for the treatment of canine OA (24). Concerns have been raised that the popularization of MSC is driven by commercial interests rather than the pet's best interest (23). The data presented here further question the routine clinical use of intra-articular Allo-MSC at this time. The wide availability, off-the-shelf nature, safety, and possibly lower cost make HA a potential treatment standard to which novel products should be compared (and expected to be superior to) prior to widespread clinical use. Further studies defining and investigating the potential greater clinical benefit of HMW HA for the treatment of canine OA should be considered. Future studies may consider adding a true placebo arm, more advanced data analysis of the accelerometer data [e.g., functional linear modeling (32)], and/or more frequent OGA data collection.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/**Supplementary Material**.

ETHICS STATEMENT

The animal study was reviewed and approved by Clinical Review Board and Animal Care and Use Committee of Colorado State University. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

SK, VJ, AH, TW, SD, and FD contributed to the conception and design of the study. SK organized the data and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Pilot Study on Feasibility of Sensory-Enhanced Rehabilitation in Canine Spinal Cord Injury

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Physical rehabilitation is frequently recommended in dogs recovering from acute thoracolumbar intervertebral disc extrusion (TL-IVDE), but protocols vary widely. The objective of this study was to evaluate the feasibility of incorporating sensory-integrated neurorehabilitation strategies into a post-operative rehabilitation protocol in dogs with TL-IVDE. Non-ambulatory dogs with acute TL-IVDE managed surgically were prospectively recruited to this unblinded cross-over feasibility study. Eligible dogs were randomized to start with tactile-enhanced (artificial grass) or auditory-enhanced (floor piano) basic rehabilitation exercises performed twice daily for the first 4 weeks before switching to the opposite surface for the subsequent 4 weeks. Neurologic examination, open field gait scoring, girth measurements and an owner-completed feasibility questionnaire were performed at baseline and 2, 4, 6, and 8 weeks post-operatively. Twenty-four dogs were enrolled, 12 randomized to each order of exercises. Gait scores did not differ between the two groups at baseline, 4 or 8 week visits. All modified exercises could be performed and compliance was high. Adverse events potentially attributable to the study surface were mild, self-limiting and occurred in 2/24 dogs. The most common surface-related limitations were that the piano was slippery and that both surfaces were too short. The artificial grass was preferred by owners and dogs compared to the floor piano surface, but this was influenced by which surface was utilized first. Auditory and tactile modifications were feasible and safe to incorporate into a standardized rehabilitation protocol. This pilot study could prompt larger efficacy studies investigating the benefit of sensory-integrated rehabilitation in dogs with TL-IVDE.

Keywords: thoracolumbar intervertebral disc extrusion (TL-IVDE), disc herniation, neurorehabilitation, tactile-enhanced exercises, auditory-enhanced exercises

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INTRODUCTION

Acute spinal cord injury (SCI) occurs frequently in dogs, commonly due to thoracolumbar intervertebral disc extrusion (TL-IVDE) (1, 2). A successful outcome after TL-IVDE in dogs is typically defined as resolution of pain and regaining independent ambulation and reasonable continence (3). Physical rehabilitation is frequently recommended to facilitate improvement (4, 5) with basic rehabilitation exercises consisting of cryotherapy, passive range of motion, massage, assisted standing and assisted walking (6–17). A variety of more intensive or multimodal protocols have been described in dogs with SCI, but the primary target of most rehabilitation therapy is the motor system (8, 11–23).

Sensory stimulation as a component of rehabilitation protocols in dogs is occasionally mentioned with descriptions of toe pinching, hair brushing, and utilizing different flooring surfaces (7, 10–12, 16, 19). However, details are limited regarding how they are incorporated and evidence to support such sensory-stimulating exercises is lacking in veterinary patients. In human stroke and SCI patients, sensory integration training has been shown to improve motor outcomes (24–29). This includes preferential stimulation of sensory fibers of peripheral nerves which promotes improved somatosensory processing and augments the effects of massed practice of motor skills (25, 26). Vibratory stimulation of specific muscle groups also provides enhanced proprioceptive feedback and improves motor function in people with incomplete tetraplegia (24) and stroke (28), and can be combined with other strategies such as using visual cues (30). Rhythmic auditory stimulation during gait training improves walking performance as does real-time auditory feedback of motor errors (27, 31–33). Visual strategies such as mirroring specific actions by an unaffected limb or providing real-time visual feedback during exercises appear to similarly promote improved motor learning and execution (27, 34). The benefit of sensory-based neurorehabilitation strategies in dogs with acute SCI is unknown.

The objective of this study was to evaluate the feasibility of incorporating tactile- and auditory-enhanced exercises into a standardized, post-operative basic rehabilitation protocol in dogs with TL-IVDE. We hypothesized that sensory-enhanced exercises would be simple to perform and well-tolerated by dogs recovering from acute TL-IVDE.

MATERIALS AND METHODS

Study Animals

Client-owned dogs were prospectively recruited from the existing patient pool of the Purdue University Veterinary Hospital. Dogs had to have an acute SCI secondary to TL-IVDE resulting in non-ambulatory paraparesis or paraplegia with or without pain perception, be aged 1 to 10 years and weigh between 5 and 25 kg. The minimum weight limit was to ensure dogs were sufficiently large enough to produce sounds on the surface utilized for the auditory-enhanced exercises. The upper weight limit was chosen to facilitate adequate participation in exercises given length limitations of the study surfaces. Duration of neurologic signs had to be ≤7 days from onset of pain or pelvic limb deficits. Confirmation of TL-IVDE between the third thoracic and third lumbar vertebrae (T3-L3) was required based on computed tomography or magnetic resonance imaging. Decompressive hemilaminectomy was performed followed imaging confirmation of extruded disc material. The number of sites decompressed and whether durotomy or prophylactic fenestration were performed was at the discretion of the neurosurgeon.

Exclusion criteria included deafness, severe orthopedic or systemic disease, signs consistent with progressive myelomalacia on presentation, temperament (i.e., dogs not amenable to handling), or unwillingness to return for study rechecks. The study was approved by the Purdue Animal Care and Use Committee (protocol #201200210) and all owners provided informed consent at enrollment.

Study Design

This study was a prospective, randomized, unblinded, cross-over design clinical trial. At 48 h post-operatively, eligible dogs were enrolled, stratified based on whether or not they had deep pain perception (deep pain positive or deep pain negative) and then assigned to one of two treatment groups in a 1:1 ratio using block randomization (groups of 4) with a cross-over design. Stratification ensured an even distribution of the most severely affected dogs (i.e., deep pain negative) between the treatment groups. Group 1 participated in tactile-enhanced neurorehabilitation for 4 weeks, then auditory-enhanced exercises for 4 weeks while group 2 participated in the opposite order of exercises. Dogs were evaluated at enrollment (baseline visit) and at 2-, 4-, 6-, and 8-weeks post-operatively.

Study Procedures

Touch (i.e., Artificial grass[1]) or sound (i.e., Floor piano mat[2]) modifications were incorporated into a standardized post-operative rehabilitation regimen which included: passive range of motion (PROM), assisted standing and weight-shifting and assisted walking. A 2-foot-wide by 6-foot-long strip of artificial grass and a 29-inch-wide and 70-inch-long child's floor piano were utilized as the tactile- and auditory-enhancements, respectively (**Figure 1**). The floor piano had a smooth surface. Passive range of motion was performed in a standing position where each pelvic limb was manually manipulated through range of motion (bicycling) at each joint to simulate limb movement during walking (**Supplementary Video 1**). The plantar surface of the paw was brought in contact with the study surface with each repetition, either touching the grass or touching and producing a sound on the floor piano. This was repeated 20 times per leg at each session. Assisted standing and weight shifting consisted of supporting the dog to stand squarely with all four limbs positioned on the study surface (**Supplementary Video 2**). The hips were then gently shifted from left to right and front to back for 5 min at each session. For PROM and assisted standing and weight shifting exercises, the use of the owner's hands, a sling, a physiopeanut or modified foam roller were utilized to provide hindquarter support as needed until dogs were able to support their own weight against gravity. Assisted walking was performed by repeatedly walking the dog on a leash across the study surface for 5 min per session (**Supplementary Videos 3, 4**). Hindquarter support was provided with the use of a sling or harness until dogs were independently ambulatory. When utilizing the floor piano for standing and walking exercises, the goal was to produce

[1]Greenline Jade 50 15ft Wide x Cut to Length Artificial Grass, Home Depot, homedepot.com.

[2]Click N' Play Gigantic Keyboard Play Mat 70 x 29 inches, Amazon, amazon.com.

FIGURE 1 | Examples of the artificial grass and floor piano used for sensory-modified exercises.

a sound each time the body weight was shifted or a step was taken, respectively.

All exercises were performed two times per day throughout the 8-week study period, including during initial hospitalization, starting 48-h post-operatively. Owners were sent home with the assigned study surface at the time of discharge from initial hospitalization and provided with the new study surface at the 4-week study visit. At the time of discharge and the 4-week recheck, owners were instructed verbally and via demonstrations on how to perform each exercise including how to use and incorporate each study surface.

At each study visit, the following procedures were performed: physical and neurologic examinations, open field gait scoring, body and limb circumference measurements, and an owner-completed questionnaire. Neurologic examination consisted of evaluation of mentation, gait, cranial nerves, postural reactions, spinal reflexes, presence of spinal hypersthesia, pain perception and continence. Gait was classified as normal, ambulatory paraparesis, non-ambulatory paraparesis or paraplegia. Ambulation was defined as being able to take at least 10 consecutive weight-bearing steps without falling. Gait was also scored using the validated 0-12-point open field gait scale (OFS) (35, 36). A Gulick-type 2 tape measurement device[3] was utilized for all circumference measurements and performed by trained personnel. Three circumference measurements were performed in triplicate as previously reported including caudal trunk girth and right and left thigh girth (37). Briefly, the caudal trunk measurement was performed in a standing position with girth measured around the abdomen just cranial to the inguinal folds. Limb girth measurements were performed in lateral recumbency with the circumference of the upper limb measured at 50% of the length of the femur from the greater trochanter. A questionnaire was completed by owners at each study visit (**Supplementary Figure 1**). The questions focused on compliance and feasibility regarding the ease of completion, patient tolerance and any adverse effects associated with the rehabilitation exercises or the study surface.

Statistical Analysis

As a pilot, feasibility study, a power analysis was not performed. A minimum sample size of 20 dogs was planned with the aim of providing sufficient preliminary data on our methods. Descriptive statistics were utilized to summarize enrollment and feasibility data acquired in this study. Triplicate girth measurements were averaged to provide a mean value for each dog at each visit. To account for dogs of varying size and conformation, these measurements were expressed as a percentage of the baseline values. Mean OFS scores and girth measurements at baseline, 4 and 8 weeks post-operatively were compared using a *t*-test to look for any differences between groups. $P < 0.05$ was considered significant.

RESULTS

Twenty-four dogs were enrolled with a mean age of 4.4 years (SD 2.2) and mean body weight of 9.4 kg (SD 4.5) at baseline. Breeds included 12 dachshunds, four mixed breed dogs, three French bulldogs, and five breeds represented by two or fewer dogs. Mean duration of neurologic signs prior to enrollment was 3.2 days (SD 1.2), accounting for a 48-h interval from presentation and surgery to enrollment. Twelve dogs including twoparaplegic with absent pain perception were randomized to start with exercises incorporating the artificial grass (Group 1). This group had a mean age of 3.8 years (SD 2), mean body weight 11 kg (SD 4.9) of and mean duration of signs of 3.2 days (SD 1.1). Twelve dogs including 3 paraplegic with absent pain perception were randomized to start with the floor piano (Group 2). This group had a mean age of 5 years (SD 2.4), a mean body weight of 7.7 kg (SD 3.6) and a mean duration of signs of 3.2 days (SD 1.2). Group 1 was significantly heavier than group 2 ($p = 0.04$), but no significant differences were identified between groups with regard to age or duration of signs ($p > 0.05$).

All dogs were diagnosed with TL-IVDE between T10 and L3 and underwent decompressive surgery. Surgical plan including number of sites decompressed and prophylactic fenestration varied between cases. No intra-operative complications were encountered. One dog required a second decompressive surgery 3 days after the first due early re-herniation of disc material resulting in paraplegia with intact pain perception. This dog was enrolled in the study 48 h after the second surgery (with a neurologic status of paraplegia with intact pain perception) and no physical rehabilitation exercises were performed (of any kind) until enrollment and randomization. Nineteen dogs completed all study visits (nine in group 1, 10 in group 2), one dog completed three of the four rechecks (missed 6-week visit), two dogs completed two of four rechecks (missing 6- and 8-week rechecks), one dog completed only the 2-week recheck. One

[3]Gulick II Tape Measure, Fitness Mart, GaysMills, WI.

TABLE 1 | OFS scores at each study visit.

Study visit	OFS Scores Median (range)		
	All dogs	Group 1 (grass, then piano)	Group 2 (piano, then grass)
Baseline ($n = 24$)	0 (0–4)	0 (0–1)	0 (0–4)
2-week ($n = 23$)	6 (0–9)	5.5 (0–9)	7 (1–9)
4-week ($n = 22$)	8 (2–11)	7 (2–11)	8 (2–11)
6-week ($n = 19$)	8 (2–12)	8 (3–12)	8 (2–11)
8-week ($n = 20$)	9 (3–12)	9 (3–12)	9 (3–11)

OFS, open field scale.

additional dog was euthanized within 1 week after the baseline visit (due to lack of neurologic improvement).

At baseline, seven dogs were non-ambulatory paraparetic (two in group 1, five in group 2), 12 were paraplegic with intact pain perception (eight in group 1, four in group 2) and five were paraplegic with absent pain perception in their pelvic limb toes and tail base (two in group 1, 3 in group 2). Of the dogs with available follow-up data, 16 dogs were ambulatory by 2 weeks, 17 dogs were ambulatory by 4 weeks and 18 dogs were ambulatory by 8 weeks or sooner. At study completion, 4 dogs remained non-ambulatory, of which 3 had persistently absent pain perception with varying degrees of pelvic limb motor. Gait scores across study visits are outlined in **Table 1**. There were no significant differences identified in OFS scores between groups at baseline, 4 and 8-week study rechecks ($p > 0.05$).

Proprioception (paw placing) was absent in all dogs at baseline. By study completion, proprioceptive placing had completely normalized in five dogs, including two dog from group 1 and three dogs in group 2, but remained delayed or absent in the remainder. Mean girth measurements expressed as a percentage of baseline values are outlined in **Table 2**. Caudal trunk girth was decreased at 4 weeks compared to baseline in both groups; by 8 weeks post-operatively, this had returned to baseline in group 2 but remained lower in group 1. Left and right thigh circumference measurements did not demonstrate clear trends. Changes were generally small and no significant differences between groups over time were identified ($p > 0.05$).

Adverse events during the course of the study occurred in 5/24 (21%) dogs, including two dogs in which it was considered attributable to the tactile or auditory modifications. In one dog, the piano noise was noted to be particularly aversive and another dog developed a superficial abrasion on the dorsum of the right pelvic limb paw during the study period when using the artificial grass. Neither event required intervention and the exercises were continued by both owners. Additional adverse events reported by owners in three dogs were related to their neurologic status. This included one dog initially paraplegic deep pain negative that regained pain perception by discharge but was euthanized at 1 week post-operatively due to lack of recovery of function. Another dog initially recovered uneventfully but had a recurrence of paraplegia at 4.5 weeks post-operatively due to a presumptive re-herniation. This dog was managed conservatively and had regained independent ambulation by the next study visit. A third dog was noted by the owner to be intermittently, mildly painful when performing the daily exercises during the first 2 weeks post-operatively. No adjustments to the dog's analgesic protocol were required.

In 20/24 (83%) dogs, all modified exercises were performed as instructed, while owners of four dogs reported that they were unable to perform all of the exercises twice daily at some point during the study period. In 3 dogs, this was reported for a single 2-week period while one owner reported incompletely performing the exercises over a duration of 4 weeks. The reasons cited included being busy or other scheduling conflict in 3 dogs and fear of worsening status in one dog that suffered a presumptive re-herniation.

All exercises were able to be performed with the modifications. However, ease of use varied between dogs and surfaces. Summarizing owner-reported feasibility across all study visits in which data was available, 13/22 (59%) owners reported that the grass was easy to use while 9/22 (41%) owners reported at least once that use was associated with mild difficulty. Six of 20 (30%) dog owners reported that the piano was easy to use while 14/20 (70%) owners rated on at least one occasion that this surface was mildly difficult (12/20, 60%) or hard to use (2/20, 10%). No trends over time during the 8-week study period regarding ease of use for each surface were identified.

Feedback relayed via the questionnaire could be subdivided into comments that were related vs. unrelated to the surfaces. Positive experiences related to the the artificial grass were reported in two dogs including one dog that 'loved the grass' and another where it 'reminded the dog of being outside.' Positive experiences related to the floor piano were also reported in two dogs including one dog that 'liked making noises' and another where it 'seemed like a game.' The most common surface-related limitations or negative experiences reported were that the piano was too slippery and both the grass and piano were too short, especially when performing the walking exercises. These were noted in ∼25 and 15% of questionnaire responses, respectively. Less than 10% of responses indicated that dogs initially disliked or were scared of the artificial grass texture or the piano noises, though all were reported to get used to it on subsequent responses. One dog weighing 6.4 kg was noted to be too small to consistently make noise on the floor piano when performing the exercises, though this was not specifically reported in the seven other dogs weighing the same or less (5.4–6.4 kg) than this dog.

There were non-surface related comments provided in about 27% of questionnaire responses and these were generally attributable to behavioral limitations associated with performing the exercises. The most commonly reported behavioral difficulties included that the dog got distracted or tried to move away from the owner and the designated surface/exercise area, that the dog was not cooperative when performing the exercises, that the dog became bored or frustrated during the 5-min sessions for each exercise, and that the duration of the exercises was too long. Owners also noted that these limitations became more frequent or problematic to overcome as their dogs improved and regained more pelvic limb function.

TABLE 2 | Mean thigh and body girth measurements at the 4- and 8-week study visits, expressed as a percentage of baseline values.

Study visit	Group 1 (grass, then piano)			Group 2 (piano, then grass)		
	Caudal trunk girth % (SD)	Left thigh girth % (SD)	Right thigh girth % (SD)	Caudal trunk girth % (SD)	Left thigh girth % (SD)	Right thigh girth % (SD)
Baseline	100	100	100	100	100	100
4-week	94.7 (8.8)	102.7 (8.2)	98.8 (14.0)	94.2 (8.5)	104.2 (12.4)	100.3 (11.7)
8-week	95.6 (4.1)	98 (14.4)	100.4 (13.3)	100.9 (8.0)	103 (13.1)	103.0 (12.9)

TABLE 3 | Owner and dog surface preference stratified by group allocation.

Dog number	Group 1 or 2	Owner surface preference	Dog surface preference
1	Group 1	Piano	Piano
2	Group 1	Piano	Piano
3	Group 1	Grass	Both
4	Group 1	Grass	Both
5	Group 1	Both	Both
6	Group 1	Both	Both
7	Group 1	NA	NA
8	Group 1	NA	NA
9	Group 1	Grass	Grass
10	Group 1	NA	NA
11	Group 1	Grass	Grass
12	Group 1	Grass	Both
13	Group 2	Grass	Grass
14	Group 2	Grass	Grass
15	Group 2	Grass	Neither
16	Group 2	Grass	Grass
17	Group 2	NA	NA
18	Group 2	Grass	Grass
19	Group 2	Grass	Grass
20	Group 2	Grass	Grass
21	Group 2	Grass	Grass
22	Group 2	Grass	Grass
23	Group 2	Piano	Grass
24	Group 2	NA	NA

Group 1, grass first; Group 2, piano first; NA, data not available.

Of the 20 dogs that completed an 8-week study visit, owners of 14 dogs preferred the grass, three preferred the piano, two indicated an equal preference for both and one did not provide an answer. Eleven owners indicated that their dog preferred the grass, two thought their dog preferred the piano, five indicated their dog liked both surfaces equally, 1 owner reported that their dog disliked both surfaces equally, and one owner did not provide an answer. The surface preferences varied by group (**Table 3**). When starting with the piano first (group 2), 9/10 owners and 9/10 dogs preferred the grass. However, when starting with the grass first (group 1), 5/9 owners and 2/9 dogs preferred the grass.

DISCUSSION

This is the first study specifically investigating sensory-enhanced rehabilitation exercises in dogs recovering from acute TL-IVDE. Our results demonstrated that simple auditory and tactile modifications were feasible and safe to incorporate into a standardized rehabilitation protocol. While both surfaces were generally well-tolerated, dog behaviors independent of the surface contributed to challenges in performing the exercises during the study period. This preliminary information could be used to design larger efficacy studies investigating the benefit of sensory-enhanced neurorehabilitation and to continue to optimize rehabilitation protocols in this population.

Incorporating two different, readily accessible surfaces, a piece of artificial grass or a child's floor piano, we provided a simple means to enhance sensory feedback as part of a basic post-operative rehabilitation protocol consisting of PROM, assisted weight shifting and assisted walking. There is very limited detail from prior studies in veterinary patients regarding how exercises with a sensory component are incorporated (8, 10–12, 16, 19). Importantly, sensory stimulation exercises in the post operative veterinary neurologic patient typically center on the owner or rehabilitation professional stimulating the patient's feet, with activities like toe pinching, tickling or rubbing having been described (6, 8, 10, 11). This study was different in that the sensory stimulation was initiated by the patient's foot landing on the artificial grass or floor piano surface, and therefore, incorporated into the exercises themselves. Specific sensory-integrated techniques are utilized in people with SCI as well as other conditions such as stroke (24–28). These approaches allow intact sensory systems (e.g., auditory system) to provide appropriate input in the form of specific sensory cues during various motor training tasks to aid in recovery or compensation of an impaired sense (e.g. propioeption) after injury (38, 39). Music, through its ability to stimulate memories and the so-called memory-movement connection, has also been described as a rehabilitation strategy to promote muscle memory and enhance movement (40). A variation on this, known as cognitive multisensory rehabilitation, uses multisensory input to restore brain connectivity relating to awareness and pain perception that is impaired after SCI (41). Reported benefits include rebuilding the mind-body connection, improving body awareness and reducing neuropathic pain (41). Sensory-integrated neurorehabilitation approaches have also been associated with improved motor outcomes and enhanced overall functional recovery (24–28, 34, 38, 39).

Given the potential benefits demonstrated by human neurorehabilitation studies combined with the dearth of information in veterinary SCI patients, our rationale was to explore novel sensory stimulation integrated into a standardized rehabilitation protocol. We demonstrated that the tactile or auditory adaptations were simple to apply and that the modified exercises could be performed by veterinary professionals and owners with no specific training or skills. Additionally, the dogs of this study with severe SCI secondary to TL-IVDE were amenable to both the tactile and auditory sensory stimulation, regardless of their neurologic status or recovery trajectory. Patients who were paralyzed or severely paretic and also those who regained independent walking tolerated both types of sensory stimulation. In addition to feasibility, no substantial adverse events directly attributable to the surfaces or exercise modifications were encountered. Initiation of exercises at 48 h post-operatively was well-tolerated which is consistent with other clinical trials of post-operative physical rehabilitation (8, 17).

While this study was not designed to evaluate efficacy, we utilized open field gait scoring, proprioceptive placing and caudal trunk and thigh girth measurements to evaluate outcomes. No significant differences were identified in these measures between the two treatment groups at 4 or 8 weeks post-operatively, but there was no control group. In addition to incorporating controls and blinding evaluators, outcome measures that can quantify the potential influence of a sensory-integrated approach would help to evaluate the efficacy of our methods. For example, quantitative sensory thresholds have been established in dogs with acute SCI (42–45) and could be used to evaluate if sensory stimulation aids in re-establishing more normal thresholds after injury. Additionally, the F-response and H-reflex provide information on motor neuron pool excitability in dogs with acute and chronic SCI (46, 47). These electrodiagnostic tests could help to objectively determine if sensory enhanced exercises provide appropriate afferent input to positively impact motor neuron pool excitability and, in turn, contribute to motor recovery. Body weight distribution has also been quantified in dogs after SCI (37) and could be used with girth measurements and proprioception to determine if sensory interventions intended to improve limb awareness affect pelvic limb weight distribution and muscle mass. Evaluation of nuanced gait parameters such as velocity, cadence and stride length are utilized in human stroke patients undergoing rehabilitation (48, 49). Treadmill-based stepping and coordination scores are validated in dogs with SCI and could be similarly utilized to objectively measure rehabilitation progress (50). Tailored outcome measures could provide important evidence of a link between an enhanced, integrated sensory environment and improved functional recovery after SCI in dogs.

While all modified exercises were feasible, owner feedback highlighted several limitations regarding ease of completion. The short length of both the artificial grass and floor piano as well as the slippery surface of the piano were recurrent comments. This suggests that additional refinement of our techniques for incorporating sensory modifications is needed to improve feasibility, ensure appropriate compliance and optimize the potential benefit. Future adjustments to the tactile-enhanced exercises could include using a textured surface of longer length or incorporating expanded tactile modifications, including taking advantage of natural outdoor surface variations on assisted walks. Providing varied terrain (e.g., tall grass, gravel, etc.) has been mentioned for dogs with recovering from disc herniation (12), but specific protocols have not been established. Providing auditory feedback via an alternative method other than the floor piano might eliminate the body size restrictions and the need to utilize a slippery surface in non-ambulatory dogs. Sound, delivered in the form of musical notes with beat and rhythm, might also be most advantageous in the later stages of gait refinement and coordination as compared to earlier stages of regaining movement after SCI (32, 33, 51). Rhythmic auditory stimulation has been incorporated into rehabilitation programs following a variety of conditions in people including SCI, stroke and movement disorders (48, 51–54). Rhythmic auditory stimulation is based on the idea of entrainment, in which rhythmic patterns produced by sounds or music directly improve movement timing and efficiency (55). This sensory technique can be combined with treadmill training to improve gait speed and balance and could be adapted for dogs. Therefore, it is possible that timing of certain types of sensory stimulation is important and that auditory integration might be more useful once a dog is more functional or even ambulatory. Another alternative strategy could be utilizing auditory cues to highlight mistakes. This has been used to improve motor performance in people with stroke (31). Future larger scale efficacy studies are warranted comparing different types of tactile and auditory stimulation to each other in an ongoing effort to optimize rehabilitation protocols, including how best to incorporate sensory integration in both the hospital and home-care settings.

Owner reported compliance was generally high throughout the study, but owner feedback also commonly focused on non-surface related issues. This included things such as dog boredom, distractability or lack of cooperation for performing the exercises, which were reported to worsen as pelvic limb function improved. In prior studies in which at-home rehabilitation regimens are recommended (10–12, 17), sparse information is provided regarding if there was adherence to protocols or if any challenges were encountered in the proper execution of the exercises by owners. We do not have baseline data on compliance in performing these exercises without the sensory modifications. However, our results underscore that dog behavior could substantially impact proper performance of prescribed exercises and owner perception of the recovery process and willingness to engage in at-home protocols. In people with SCI, explicitly outlining daily tasks and recommended exercises provides clear expectations, structure and consistency which in turn improves compliance with rehabilitation participation (56). While there are obvious differences between motivating a dog vs. onself to participate in at-home rehabilitation, our findings support that behavioral factors should be considered when developing an at-home therapy regimen. Additionally, dynamically acquiring and responding to owner feedback might improve both owner and dog participation.

At study completion, 70% of owners preferred the grass and 55% of owners thought their dogs also preferred the grass while just 15% of owners and 10% of dogs preferred the piano. While this might support a true preference for the artificial grass surface, there was a discrepancy based on whether dogs were randomized to group 1 (grass first) or group 2 (piano first). When rehabilitation exercises were initially performed on the piano, the vast majority of the dogs and owners preferred grass as compared to the piano. The opposite, however, was not the case; when dogs used grass for the first half of the study, owner preference for grass over the piano was less decisive and dog preference was essentially equally spread between the surfaces. Therefore, the role of the order of surfaces and the dogs' neurologic status during the recovery period must be considered as factors impacting this preference. Similar to previously published data on recovery rates (57), the majority of dogs in this study regained independent ambulation within the first 4 weeks post-operatively. Thus, when pelvic limb motor function was worse during the first half of the study, the smooth surface of the floor piano likely made it more difficult to perform the exercises while the textured surface of the artificial grass could have provided better traction. This might help to explain why owners of dogs randomized to group 2 (piano first) more strongly favored the artificial grass. Once greater functional status was achieved, the slippery nature of the piano might have been less of a detractor and could account for the more even distribution of preference in dogs randomized to group 1 where the piano was not utilized until the latter half of the study. Another potential contributing factor is that group 2 was significantly lighter than group 1. Being lighter makes it harder to make noise on the floor piano and could exacerbate the lack of traction further influencing the preference toward the artificial grass.

Similarly, all owners whose dogs completed the study but did not regain ambulation during the 8 weeks of follow-up, preferred the grass to piano. In these more severely affected dogs, traction and support from the artificial grass might have facilitated more easily performing exercises compared to the smooth surface of the piano. While pelvic limb tone and ability to bear weight against gravity improved over the course of the study among the dogs that remained non-ambulatory, this might not have been enough to improve the ease of completion of exercises on the floor piano (relative to the grass) and influenced the owner's preferred surface.

Overall, this pilot project demonstrated that sensory integrated rehabilitation was feasible in dogs recovering from severe SCI and provides a framework to continue to investigate multisensory rehabilitation protocols incorporating visual, auditory, tactile, or somatosensory stimulation, or a combination of approaches. These preliminary results will be useful to design future, larger scale efficacy studies on sensorimotor integration into intensive, staged rehabilitation protocols in dogs recovering from SCI.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Purdue University Institutional Animal Care and Use Committee (protocol # 201200210). Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

MJL and SAT participated in study design, data acquisition and analysis, manuscript preparation, and editing and review. JB, BL, NP, and RY participated in data acquisition and analysis and manuscript editing and review. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.921471/full#supplementary-material

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ORIGINAL RESEARCH
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Assessment of Sex, Age, and Metabolism Relationships to Serum Thyroid Concentrations in Retired Alaskan Husky Sled Dogs

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Sled dogs are purpose-bred dogs selected for endurance work. Prior studies in racing dogs showed that serum thyroid parameters (total T4, free T4, and T3) are lower than the reference range in approximately 25% of dogs. Whether this is related to training, breeding, or body condition remains unclear. We hypothesized that retired sled dogs of normal body condition (9–13 years old) would have predominantly normal serum thyroid parameters and that serum thyroid status would be correlated to energy consumption based on metabolic body weight. Eighty-six sled dogs who were deemed healthy on physical exam, not on confounding medications, and without a prior diagnosis of hypothyroidism were included. All dogs' mean body condition scores were 5.1 ± 0.4 and body weight 24.5 ± 4.2 kg at fasting blood collection with stable dietary intake for 3 months before sampling. The total T4, free T4, and T3 serum concentrations were 23.4 ± 9.1 nmol/L, 9.53 ± 4.3 pmol/L, and 0.93 ± 0.39 nmol/L, respectively, with 38% lower than the reference range for total T4, 45% for free T4, and 37% for T3. All dogs were negative for thyroglobulin antibody, and TSH results were within normal ranges. Pearson's correlates based on kilocalories consumed on a metabolic body weight basis for total T4 ($R = 0.14$), free T4 ($R = 0.01$) and T3 ($R = 0.23$) showed poor correlation. No differences were observed between thyroid hormones and age, breed, or sex. Inactive, retired sled dogs can be misdiagnosed with hypothyroidism; therefore, our data suggests that misdiagnosis of hypothyroidism can occur and that the racing Alaskan sled dog has a unique reference range that should be considered when assessing serum thyroid status.

Keywords: Alaskan Husky, sled dog, metabolic energy, thyroid, free T4, total T4

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INTRODUCTION

Thyroid hormones play several essential roles in the dog. Thyroid hormones have been proposed to increase most tissues' metabolic rate and oxygen consumption, induce positive inotropic and chronotropic effects, play a role in the hemostatic system, influence catabolism in muscle and adipose tissue and play a role in cholesterol synthesis and degradation (1, 2). The most common thyroid disorder diagnosed in dogs is hypothyroidism, a clinical condition of low circulating levels of thyroid hormones (2, 3). It is generally thought that decreased thyroid hormone levels play a significant role in the lower metabolic rate in dogs and has been rarely examined in population studies comparing metabolizable energy intake to serum thyroid status. Sighthounds, such as young, healthy racing greyhounds and northern arctic breed dogs, have been found to have lower thyroid hormone concentrations, sometimes below standard reference ranges (2, 3). It has been suggested that breed-specific thyroid hormone reference ranges would be helpful for certain dog breeds, including whippets and Alaskan Husky (AH) sled dogs (4). There is considerable debate surrounding the many possible causes of low thyroid hormone concentrations. Potential contributors of low thyroid hormones include exercise, medications, age-related change, environmental temperature, circadian rhythm effect, seasonal differences, macronutrient differences or micronutrients (i.e., iodine) in the diet, and a negative energy balance associated with working conditions (2, 3, 5–9). Euthyroid sick syndrome can also confound accurate thyroid function assessments (3).

Evanson and colleagues documented exercise significantly decreased total T4 (TT4) and free T4 (fT4) during peak training compared to the off-season (7). Other work by Panciera and colleagues found reduced thyroid hormone levels (T3 and total T4) after an approximately 1,000-mile race (8). Two studies also found an overall decrease in sled dogs' thyroid hormone concentrations during the off-season and when not racing (1, 8). Thus, suggesting that exercise alone was not responsible for the lower thyroid concentrations and that kennel management, diet, and environment may also play a role in serum thyroid concentrations in endurance racing AH sled dogs.

A year-long study following a population of outdoor kenneled Beagles found that total T4 and free T4 increased in November, possibly due to the needed increased basal metabolic rate during cooler temperatures (6). However, Alaskan Husky sled dogs live outside year-round and adapt to the cooler temperatures of their environment. Aging may also influence circulating thyroid hormone levels, with a mild decrease of T4 observed in older pet dogs (3). However, older healthy non-hypothyroid pet dogs' T4 values will usually fall within the low end of the standard reference range. A study did find that Salukis and Sloughis T4 levels decline at the same rate as non-sight hound breed dogs (2). Aging and inherent breed differences can often result in incorrectly diagnosed hypothyroidism leading to inappropriate thyroid supplementation (10, 11). However, no studies to date have examined thyroid hormone levels in aged Greyhound or Alaskan Husky sled dogs. Currently, no studies have examined metabolizable energy intake and thyroid hormone concentrations of older, inactive kenneled sled dogs in ideal body condition in a thermoneutral environment.

We hypothesized that retired sled dogs at ideal body condition (5/9), regardless of sex, would have predominantly normal serum thyroid parameters and that serum thyroid status would correlate with metabolizable energy consumption based on metabolic body weight and there may be significant correlation with TSH and thyroid hormone status. We also investigated whether age, sex (female spayed, male intact or castrated male), or breed (Alaskan Husky vs. Alaskan Husky + Hound cross) influenced thyroid parameters.

MATERIALS AND METHODS

Ninety-Six retired sled dogs from across the country currently being monitored as part of a long-term aging study were included. All dogs were obtained as retirees from 14 kennels within the United States between the ages of 8 and 11 years of age. All Alaskan huskies were from mixed lineages of purpose bred racing sled dogs. The dogs acclimated to the kenneled environment and were housed in an indoor thermoneutral kennel facility (76°F) for at least 1 year prior to our study and were deemed healthy on physical exams at the onset of this study. We examined current medical records to ensure none of the dogs were receiving any medications that would affect thyroid hormone levels and had no prior diagnosis of hypothyroidism. Dogs were not on any concurrent medications or medications within 1 month prior to the blood draws including antibiotics, immunosuppressants, or non-steroidal anti-inflammatory medications. Of the 96 dogs assessed 86 met the inclusion criteria for the study. All of the dogs were on the same diet (Annamaet Extra dry food or ProPlan Chicken and Rice Savory formula canned food). One dog was on a hydrolyzed kibble (Purina HA) due to presumptive IBD and was well controlled on this diet alone and no other concurrent medications. Dogs were fed to achieve ideal body condition (BCS 5/9) for 3 months (12). Once they reached ideal body condition, they were observed for maintenance of body weight and metabolizable energy fed for an additional 3 months before drawing 12-h fasting blood samples between 10 am and 2 pm on two separate mornings to avoid diurnal fluctuations. The New York State Diagnostic Laboratory measured serum concentrations of thyroid-stimulating hormone (TSH), total thyroxine (TT4), free thyroxine (fT4—by equilibrium dialysis), 3,3',5—triiodothyronine hormone (T3), and thyroglobulin antibody. Body condition scores, metabolizable energy fed based on calculation from manufacturer label, breed type (AH vs. AH-Hound mix), age, and sex were also recorded.

TT4, fT4, T3, and TSH were compared to standard established reference ranges from the Cornell Endocrinology Laboratory. Body condition score and weight were averaged at the end of the three-month observation period. Metabolic body weight was calculated based on the equation $BW(kg)^{0.75}$. Metabolic energy was assessed based on the food (Annamaet Senior Dog Food, Sellersville, PA, Proplan Performance Savory Chicken Dog Food, Nestle-Purina; St. Louis, MO, or both) that was fed to each dog based on the manufacturers' assessments from modified Atwater equations as kilocalories per cup or per can fed to each dog as one daily meal. The diet fed is an American Association of Feed Control Officials approved diet (adequate in all nutrients including iodine) which is sold nationally. Metabolizable energy intake was then divided by metabolic body weight to provide kilocalories consumed per kilogram of metabolic body mass. Pearson's correlations were performed on kilocalories fed on a metabolic body weight basis to assess the relationship with thyroid hormone concentrations and for assessment of TSH correlation to serum thyroid hormone indices. We calculated R values, assessed as R < 0.3 being weak correlations, R > 0.3–0.5 modest correlations, R > 0.5−0.7 moderate correlations, and >0.7 strong correlations. Sex, breed type, and age were assessed for normality of hormone concentrations utilizing a Shapiro Wilks test. Numerical data are presented as mean +/- standard deviation. A T-test for two way comparisons or ANOVA for greater than two group comparisons for TT4, fT4, and T3, concentrations across sex (MN, MI, FS) breed type (Alaskan Husky vs. Alaskan husky + Hound mix) and age (<10, 11, 12, and 13). A P-value of <0.05 established significance.

RESULTS

After exclusion based on medication status and negative for thyroglobulin antibody and TSH results within normal ranges, 86 dogs were included in the data analysis. The mean body condition score was 5.1 ± 0.4, and the mean body weight was 24.5 ± 4.2 kg at the time of blood draws. Mean serum TT4, free T4, and T3 were 23.4 ± 9.1 nmol/L, 9.53 ± 4.3 pmol/L, and 0.93 ± 0.39 nmol/L, respectively, with 38% of the dogs being lower than the reference range for total TT4, 45% for fT4, and 37% for T3 (**Figures 1A,B**). Pearson's correlates were calculated based on kilocalories consumed on a metabolic body weight basis for TT4 (R = 0.14), fT4 (R = 0.01), and T3 (R = 0.23), showing poor correlation; with only T3 showing significance (p = 0.03: **Figures 2A–C**). Additionally, correlation assessment of TSH status on serum fT4 (R = 0.14) TT4 (R = −0.28) and T3 (R < 0.01) were considered weak and not statistically significant.

Sixty-three AH and 23 AH-hound mixed breed dogs were assessed for serum thyroid parameters. Normality testing using Shapiro Wilks testing revealed normality of the data set when assessing sex, breed, and age across groupings leading to parametric statistical testing (ANOVA or unequal variance T-Tests). The TT4, fT4 and T3 between AH (22.6 ± 8.7 nmol/L; 9.12 ± 4.25 pmol/L; 0.91 + 0.37 nmol/L) vs. AH-Hound mixes (25.37 ± 10.0 nmol/L; 10.66 ± 4.47 pmol/L; 0.97 ± 0.43 nmol/L) were not significantly different. Across the population there were twenty-four dogs that were 10 years or younger, thirty-eight 11 year old dogs, sixteen 12 year old dogs and nine 13 year old dogs. The TT4, fT4, and T3 were not significantly different across age stratified at ≤10 (22.0 ± 7.1 nmol/L; 9.8 ± 3.8 pmol/L; 1.0 ± 0.31 nmol/L), 11 (24.1 ± 10.7 nmol/L; 9.51 ± 4.72 pmol/L; 0.86 ± 0.38 nmol/L), 12 (24.9 ± 9.3 nmol/L; 10.66 ± 4.67 pmol/L; 0.96 ± 0.52 nmol/L) or 13 (20.0 ± 5.7 nmol/L; 6.72 ± 3.01 pmol/L; 0.86 ± 0.40 nmol/L) years of age. As all females in the colony were spayed ∼1 year or more prior to assessment the population consisted of 42 FS, 11 MC, and 34 MI dogs. When assessing sex, no significant differences were observed in TT4, fT4, or T3 across FS (23.9 ± 8.4 nmol/L; 9.82 ± 4.11 pmol/L; 0.86 ± 0.38 nmol/L), MC (21.6 ± 6.4 nmol/L; 7.87 ± 3.2 pmol/L; 0.80 ± 0.37 nmol/L) or MI (23.2 ± 10.7 nmol/L; 9.74 ± 4.88 pmol/L; 1.05 ± 0.37 nmol/L).

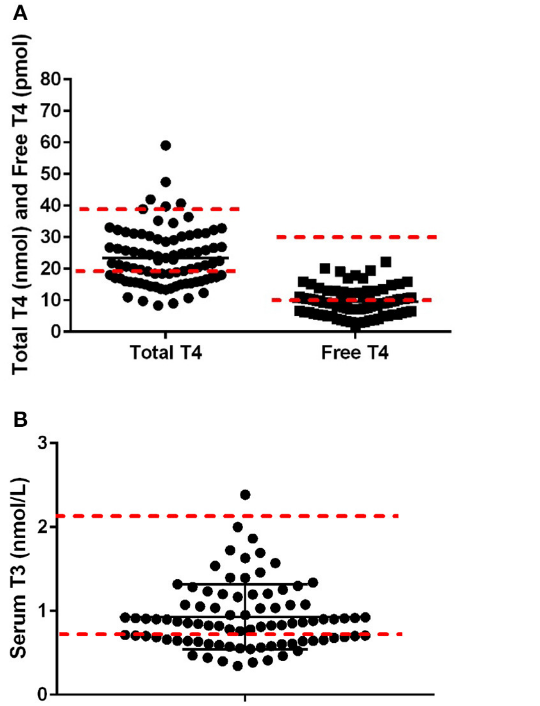

FIGURE 1 | (A) Serum concentrations of total thyroid hormone concentration (range 18–38 nmol/L) and free thyroid hormone (range 8–28 nmol/L; n-−86) in Alaskan Huskies. **(B)** Serum concentrations of T3 hormone concentration (range 0.8–2.1 nmol/L; n-−86) in aging Alaskan Huskies. Red dashed lines are the lower higher reference range based on Cornell University Diagnostic Laboratory Endocrinology Lab.

DISCUSSION

Our study sought to examine the relationship between thyroid hormones and dietary energy intake, age, breed, and sex in a cohort of AH dogs. Interestingly, we did not find any robust correlation between thyroid parameters and metabolic energy requirements in our cohort. Notably, thyroid hormone concentrations were measured below the reference interval in many dogs in our sled dog population without increased TSH to implicate hypothyroidism. TSH elevations are routinely used to help rule in clinically significant thyroid disease as a dysfunctional negative feedback, however we found no correlation to serum thyroid hormone status which is not surprising as TSH is 100% sensitive, yet only 60% specific for diagnosis of thyroid disease making our findings realistic (13).

Eales' 1988 literature review concluded that "mammalian thyroidal response to food ingestion is complex and involves many interrelated levels of thyroid function (14)." The exact relationship between food ingestion and thyroid hormone levels is not entirely understood. Eales found that thyroid T4 and T3 levels decreased in fasted dogs to a similar degree as fasted humans. He postulated that the production of T4 and T3 could be related to energy intake, especially carbohydrates. Daminet et al. examined thyroid hormones in obese dogs, lean dogs, and

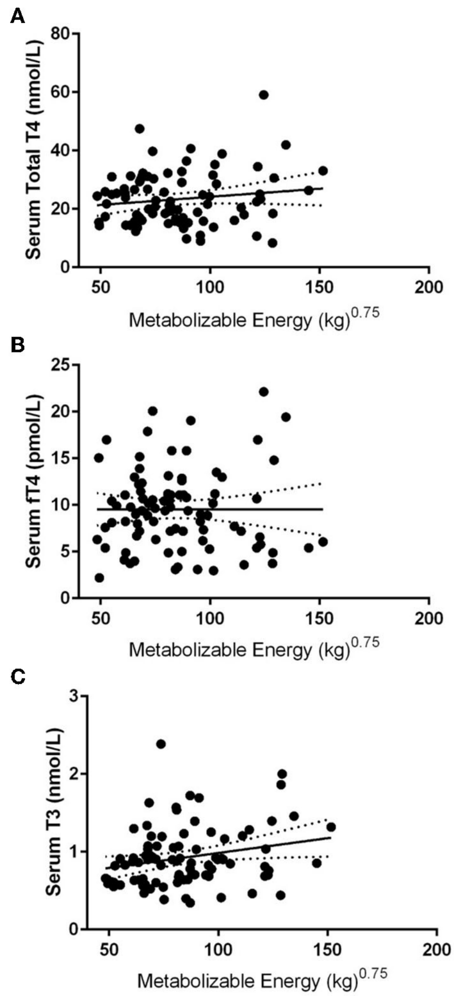

FIGURE 2 | Pearson linear regression statistics comparing various thyroid hormone concentrations vs. metabolizable energy intake in 86 Alaskan Sled Dogs. **(A)** Linear regression with 95% confidence intervals of TT4 to metabolizable energy showing weak insignificant correlation ($R = 0.14$). **(B)** Linear regression analysis with 95% confidence intervals of fT4 to metabolizable energy showing weak insignificant correlation ($R = 0.01$). **(C)** Linear regression analysis with 95% confidence intervals of T3 to metabolizable energy showing weak significant correlation ($R = 0.23$: $p = 0.03$).

obese dogs while on a weight loss diet and found that total T3 and T4 were higher in obese dogs than lean dogs while remaining within the normal reference range (15). Interestingly, the dogs with higher T3 levels required more time to achieve ideal weight regardless of starting body condition score (15). Dogs consuming a weight loss diet had lower total T3, TT4, and TSH concentrations; however, significance was only observed in total T3 and TSH. Our results showed a very weak correlation between metabolizable energy and T3 thyroid hormone, suggesting a potential association similar to the findings of Daminet and colleagues'. Daminet et al. postulated that the lower T3 observed was due to undernutrition. A low total T3 is commonly seen in euthyroid sick syndrome dogs; however, neither undernutrition nor euthyroid sick syndrome were factors in our study (15).

Other possible hormones that could be affecting T3 include testosterone and cortisol. Prior research found that thyroid hormones have a role in regulating semen quality by altering testosterone levels in men and young boys (16). In one study, healthy azoospermic Labrador retrievers had higher thyroid levels and lower testosterone levels (17). These thyroid hormones were high normal, or slightly above the normal reference range. Our study evaluated a mixed population of male and female sled dogs, some of which were neutered males, with lower thyroid hormones than the reference range. None of the intact males had higher thyroid hormone concentrations than neutered males or spayed females. This discordance may be due to our population's difference in breed and age compared to the Labrador study or the late age when most dogs in our study were sterilized. Unfortunately, little is known about the effects of estrogen on thyroid hormone status and our cohort was spayed not allowing for any associations to be derived revealing a limitation of the study which cannot be addressed. Additionally, our population of neutered males vs. intact males was skewed toward far more intact males which makes our results somewhat tenuous and further study in intact males and females vs. non-sexually intact dogs is worth further study.

Glucocorticoids suppress the hypothalamus-pituitary-thyroid axis reducing thyroid hormone levels. High endogenous cortisol was linked to a significant decrease in TT4, and fT4 to a lesser extent, while an anti-inflammatory dose of prednisone caused a decrease in T3 (18). The present study excluded all dogs with any indication of hyperadrenocorticism or were receiving any exogenous prednisone. Therefore, our results of low thyroid hormones are not iatrogenic in nature, with just over 1/3rd of our population having low TT4 levels and nearly half displaying low free T4 concentrations. Other medications such as phenobarbital, potassium bromide, non-steroidal anti-inflammatory drugs, and sulfonamides can cause lower thyroid hormones (19). The dogs evaluated in our study were not receiving any such medications, suggesting a global breed effect. We postulate that much of the prior literature in sled dogs documenting lower than normal serum thyroid condition could have been due to the exercise and intermittent negative energy balance. Our colony was kept within ideal body condition 5/9 and were not exercised and still showed even greater percentages of dogs with low serum thyroid status strongly implicates a breed or age effect.

Most other studies evaluating thyroid hormone levels in Alaskan Huskies and other sighthounds are conducted in younger dogs that are still active in sport or as companions. This study is the first to examine geriatric sled dogs, which may influence our reported range. The Scott-Moncrieff review stated that a progressive decline in T4 is seen in older healthy dogs as an age-related change (2). This was examined in Beagles and Labradors over the age of 6 years and found to have decreased fT4, TT4, and T3 in the older group compared to dogs under 6 years old (2). Scott-Moncrieff cited several possible reasons for this decline, including altered responsiveness of the thyroid gland, decreased biologic activity of TSH with age, and subclinical thyroid pathology (2). In the German Shepherd dog, a study of

57 dogs stratified into six and under and over 6 years of age found that aging dogs tended to have higher TSH and lower fT4 suggesting that aging influences the hypothalamic-pituitary-thyroid axis (10). While a decrease in thyroid hormones occurred in older German Shepard dogs, the values still fell in the lower portion of the normal reference range. Our present study in older sled dogs consistently showed thyroid levels well below the reference range. Compared to the studies mentioned above, age was not associated with significant differences in thyroid hormone concentrations in our cohort. This may be due to our study population's limited age range of 8–13 years. Further examination is needed on a larger sled dog population stratified by age to determine if the thyroid values reported here accurately represent this breed and age group.

There is speculation that colder environmental temperatures and exercise could influence the carrier protein binding of T3 and T4 yielding lower values (8). It has also been proposed that the high-fat diets of competing endurance Alaskan Husky sled dogs could also contribute to lower protein binding of T3 and T4 due to increased amounts of free fatty acids displacing them (8). Panciera et al. also mentioned that mushers competing in the same environment as the Alaskan Husky sled dogs showed no difference in the values of T3, T4, fT3, or fT4 after a long-distance race giving further support that temperature alone is not responsible for globally lower thyroid hormone concentrations (8). Oohashi et al. studied seasonal influences on thyroid hormone levels in healthy outdoor dogs and found an increased fT4 and TT4 levels in November (6). They concluded that this increase was to increase the basal metabolic rate in the face of colder temperatures to maintain normothermia. Sled dogs typically live outside all year long and are very accustomed to the temperatures. The geriatric sled dogs in this study live indoors in an environment closer to what pet companion dogs live in, therefore eliminating temperature differences as an influence in our study and further suggesting that environment is not a major contributor to chronically low thyroid status in our study.

A complicating factor that we considered is that the AH breed has diverged in the past 20 years with the breeding of hounds, primarily the German Shorthaired and English Pointer, into the AH. Based on pedigree assessment, a portion of our population has at least 1/16th hound up to 3/8th hound as part of their pedigree. Therefore, we designated these dogs as AH-Hound mixes to compare to dogs from pure AH pedigrees. A recent study examining thyroid parameters found that TT4 and fT4 were significantly lower in the English Setter, Golden Retriever, and Collie than Alaskan Malamute and the Siberian Husky breeds with intermediate concentrations. Both groups differed from the Keeshond and Samoyed with the highest breed concentrations (11). Our lack of difference suggests that the penetrance of the pointer into the AH may not be sufficient to alter these concentrations when grouped, or that the Pointer breeds may also be considered on the lower end regarding serum thyroid status, which would require further investigation comparing these breeds to the traditional AH.

In conclusion, no correlation was found between the metabolizable energy and thyroid hormone concentrations. Furthermore, when compared by age, breed, or sex, there were no differences in thyroid concentrations in geriatric AH sled dogs. Environmental and metabolic factors were eliminated since the study dogs were housed in a normothermic environment and screened for abnormalities on physical exam and blood work. These results lead us to believe breed-specific thyroid hormone ranges are necessary to avoid misdiagnosis of hypothyroidism in sled dogs. Although supplementation due to this mild to moderate diminished thyroid hormone status is unlikely to be detrimental, it is more likely that clinical signs and corresponding bloodwork should be evaluated thoroughly in this breed to better understand whether supplementation is necessary considering the cost for monitoring supplementation and medicating daily.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Cornell University Institutional Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

The research idea was the genesis of all authors. HH, JL, JW, and ML performed data analysis and acquisition. All authors contributed to the drafting and revision of this manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: AG, KA, and DF were employed by Vaika Foundation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Internet Survey Evaluation of Iliopsoas Injury in Dogs Participating in Agility Competitions

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Objective: To describe risk factors associated with demographics, training, and competition for iliopsoas injury in dogs participating in agility competitions, as well as describe owner reported treatment and return to sport following injury.

Procedures: An internet-based survey of agility handlers collected risk factor data for dogs participating in agility. Owners were asked questions about demographics, training, and competition as well as injury treatment and recovery if applicable. Associations between variables of interest and iliopsoas injury were estimated with logistic regression. The final risk factor model was built via modified backward selection, with all variables in the final model showing significant associations at $p < 0.05$.

Results: Of the 4,197 dogs in the sample, 327 (7.8%) reported iliopsoas injury. The final model identified six risk factors for iliopsoas injury. A higher risk of iliopsoas injury was observed for the Border Collie breed, dogs with handlers who are veterinary assistants, dogs competing on dirt, dogs competing on artificial turf 6+ times a year, and dogs that trained with the 2 × 2 method for weave poles. Dogs that were not acquired with agility in mind were observed to have a decreased risk of injury. Factors like number of competition days and jump height were not significantly associated with risk of iliopsoas injury. Owners sought veterinary care for 88% of dogs with iliopsoas injury, including specialty care for 63%. Treatment most often included rest, home rehabilitation, formal rehabilitation, and/or oral medications. Most dogs (80%) were able to return to sport within 6 months, while 20% were out for longer than 6 months, or retired.

Conclusion and Clinical Relevance: Iliopsoas injury can necessitate a significant amount of time off from training and competition, and even lead to retirement of dogs competing in agility. Some of the risk factors identified in this study can inherently not be modified (breed, intended use, and handler profession), but can be taken into consideration for injury prevention strategies. Competition and training risk factors that can be modified, such as weave training, may help to inform guidelines for best practices in management of the agility athlete.

Keywords: agility, dog, iliopsoas, injury, muscle injuries, sports medicine, canine

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INTRODUCTION

Agility is one of the most popular international sporting activities for dogs and comes with an inherent risk for injury. Soft tissue injuries including strains, sprains, and contusions are commonly reported in agility dogs (1, 2). A recent, large-scale survey of injuries in agility dogs, found iliopsoas injuries to be the second most commonly reported injury (3). Dogs from the general population are also at risk of iliopsoas injury, with one study reporting that dogs presenting to an orthopedic service for hind limb muscle injuries were most frequently diagnosed with iliopsoas injury (4). Iliopsoas injury can result in extended absence from training and competition (5). Despite the frequency of muscle and tendon injuries seen in dogs, particularly iliopsoas injury, overall investigation in the veterinary literature is limited especially when compared to equine or human sports medicine. Recent studies have examined specific injuries, such as those involving the digits and cranial cruciate ligament, and offer more specific risk factors and potential modifications to athlete management, but none have focused specifically on iliopsoas injury (6, 7). Identifying risk factors for development of iliopsoas injury is important for advancing the areas of prevention, diagnosis, and treatment in order to improve welfare of our canine athletes.

The iliopsoas muscle is formed by the psoas and iliacus muscles and acts as an important flexor and stabilizer of the hip and vertebral column (8). The iliopsoas is prone to acute injury and strain when there is stretch while in eccentric contraction, which is common with a slip or fall, mis-jumping, or quick changes in direction (5, 8, 9). As with any muscle injury, if left undiagnosed or untreated these initial injuries can progress to become chronic in nature. Chronic iliopsoas injury is now more commonly recognized in canine athletes, and is suspected to be a result of repetitive microtraumas to the muscle secondary to altered gait mechanics (5, 8). Both acute and chronic injury can contribute to pathologic changes in muscle anatomy and physiology, evident via musculoskeletal ultrasound (5). Agility dogs diagnosed with iliopsoas injury commonly have decreased performance, reluctance to jump and lameness that is exacerbated by activity (9). On physical exam, these patients often have pain with direct palpation of the muscle belly or at the site of insertion on the lesser trochanter of the femur, and some patients have pain that is exacerbated with extension and internal rotation of the hip (5, 9). Pain is related to the primary muscle injury, and can also involve nerves or other surrounding soft tissues (5). The femoral nerve is at risk with iliopsoas injury, as it passes directly through the muscle belly of the psoas major muscle or between psoas major and iliacus muscle groups (10, 11).

Risk factors for muscular injury in both equine and human athletes are well defined and extensively studied. Determining risk factors for injury in canine agility athletes remains in its infancy, but is imperative in determining injury prevention strategies. Therefore, the primary aim of this study was to determine risk factors for iliopsoas injury in three categories: demographics, training, and competition. A secondary aim was to collect initial data on how agility dogs with iliopsoas injury were managed and how long it took for them to return to competition. We hypothesized competing more frequently and doing more runs per day would increase risk of iliopsoas injury. We also hypothesized that earlier full height jump training and full height obstacle training would increase risk of injury.

METHODS

Data from a previously described internet survey were utilized (3, 12, 13). Briefly, individuals were eligible if they had at least one dog who had competed in dog agility in the past 3 years. All owners were asked a variety of questions about demographics (both dog and handler), training factors (such as age starting training various obstacles), and competition factors (such as primary organization and details of typical trial weekends). Dogs that had ever had an iliopsoas injury that kept them from participating in agility for over a week were classified as having a history of iliopsoas injury. Follow-up questions were asked about the injury (or most significant injury if the owner reported more than one iliopsoas injury), including whether veterinary care was sought, who determined treatment, general therapeutic categories utilized, and return to competition timeframe. Specifics regarding how the injury was diagnosed, rehabilitation plans, and medication use were not asked.

Descriptive statistics (number, percent) were used to characterize treatments reported. For associations between variables of interest and iliopsoas injury, logistic regression was used with iliopsoas injury history as the outcome and variables of interest as predictors. All models were adjusted for dog age to account for differences in exposure time for injury history. Variables of interest were grouped into three blocks: demographic factors, competition factors, and training factors (12). Model building was conducted in three steps. In step 1, all variables were assessed for a possible association ($p < 0.20$) with iliopsoas injury in age-only adjusted models. Next, within each block, variables meeting criteria from step 1 were included in an initial model and then backward selection was done until all variables in the model showed some evidence of possible association at $p < 0.20$ (step 2). In step 3, all variables retained from the three models in step 2 were included in a final backward selection process until all remaining variables were significant at $p < 0.05$. We used an available case approach to missing data (after restricting to our primary sample) and analyses were conducted in Stata version 15 (3).

RESULTS

The sample of 4,197 dogs has been described previously (3, 13). Iliopsoas injury was reported by handlers for 327 (7.8%) dogs with strain the most common injury reported (12). Among those with strains ($n = 281$), 181 (64%) reported only one strain injury, while 69 (25%) reported two, and 31 (11%) reported three or more strain injuries. Owners reported seeking veterinary care in 288 (88%) of 326 cases (treatment information was missing on one), and 207 (63%) sought care from a veterinary specialist. Owners reported that treatment was predominantly determined by a veterinarian ($n = 180$, 55%), or a non-veterinary practitioner

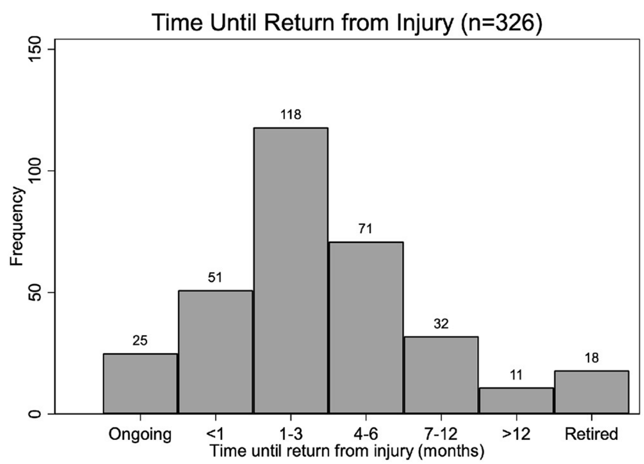

FIGURE 1 | Reported time to return to agility training and competition from iliopsoas injury among 326 dogs.

such as a chiropractor or massage therapist (n = 137, 42%), with the remainder reporting that treatment was determined by themselves or a member of their household (n = 8, 2%) or an agility friend (n = 1, 0.3%). Nearly all owners reported rest as part of the treatment plan (n = 300, 92%), with a substantial number also reporting at home rehabilitation exercises (n = 226, 69%), formal rehabilitation (n = 209, 64%), and medication use (n = 155, 48%).

Injury resolution information was available for 301 dogs (25 reported dogs actively undergoing treatment for iliopsoas injury at the time of the survey, 1 was missing). A majority of dogs (n = 169, 56%) were able to return to competition within 3 months, and 71 (24%) were able to return within 3–6 months. Forty-three dogs (14%) returned to competition after longer than 6 months, and 18 dogs (6%) were officially retired (**Figure 1**).

Many candidate variables showed some evidence of association with iliopsoas injury in age-only adjusted models (**Table 1, Supplementary Tables 1–3**). After model building, six factors remained in the final model (**Table 2**). Breed was strongly associated with iliopsoas injury, with Border Collies most likely to report an injury (OR: 1.99, 95% CI: 1.51 to 2.63). Dogs that were not acquired with agility in mind were less likely to report an iliopsoas injury (OR: 0.57, 95% CI: 0.41 to 0.78) than dogs that were acquired with agility in mind. Dogs of handlers who are veterinary assistants were more likely to report an iliopsoas injury, with relatively similar odds among the other categories of owners with and without veterinary medical training. Frequency of competing on turf and dirt were also both associated with risk of iliopsoas injury. Dogs that competed on artificial turf 6 or more times per year were more likely to report an iliopsoas injury (OR: 1.77, 95% CI: 1.32 to 2.37) compared to dogs who never competed on turf. Dogs who had ever competed on dirt were more likely to report an injury compared to dogs with no history on that surface (ORs 1.53 and 1.46 for 1–5 times per year and 6 or more times per year, respectively). Weave training method was also associated with iliopsoas injury; dogs

TABLE 1 | All factors considered in model building.

	p < 0.2 in age-adjusted models (step 1)	p < 0.2 in block model building (step 2)	Retained in final model (step 3)
Demographic factors			
Height & weight together	✓		
Breed	✓	✓	✓
Country/region	✓	✓	
Age brought dog home	✓		
How acquired (breeder, rescue, other)	✓		
Acquired with agility in mind	✓	✓	✓
Agility main sport focus	✓	✓	
Sex/neuter status			
Front dew claws			
Rear dew claws			
Docked tail			
Growth plate x-rays done	✓	✓	
Handler current age			
Handler gender	✓	✓	
Handler education			
Handler profession	✓		
Handler medical training	✓	✓	✓
Handler agility experience	✓		
Handler competed national level	✓		
Handler competed international level			
Competition factors			
Primary organization	✓		
Dog highest level achieved	✓	✓	
Jump height relative to dog height			
Approach to competition planning			
Advance competition planning	✓		
Trial weekends per year	✓		
Average runs per trial day	✓	✓	
Average days per trial weekend	✓		
Grass surface	✓		
Dirt surface	✓	✓	✓
Sand surface			
Artificial turf surface	✓	✓	✓
Foam surface			
Rubber mat surface	✓	✓	
Other surface			
Training factors			
Age started any agility training	✓	✓	
Age of first fun match	✓		
Age at first trial	✓		
Age started any jump training	✓	✓	
Age started elbow height jumps	✓		
Age started full height jumps			
Age started backside jump training	✓		
Age started backside at full height			
Age starting any tunnel training	✓		

(Continued)

TABLE 1 | Continued

	p < 0.2 in age-adjusted models (step 1)	*p* < 0.2 in block model building (step 2)	Retained in final model (step 3)
Age started curved tunnel training	✓	✓	
Age started Aframe training	✓		
Age started dogwalk training	✓	✓	
Age started teeter training	✓		
Age started any weave training	✓		
Age started sequencing with closed weaves	✓	✓	
Aframe contact behavior	✓	✓	
Dogwalk contact behavior	✓		
Teeter contact behavior	✓		
Weave training method	✓	✓	✓

Variables moved from step 1 to step 2 if they were significant ($p < 0.2$) in models adjusted for age of the dog. In step 2, backward selection was conducted within each block of variables until all variables in the block were significant ($p < 0.2$). Final model building (step 3) was done via backward selection starting with all remaining variables after the model building in step 2.

TABLE 2 | Coefficients from final adjusted model of risk factors of iliopsoas injury.

	Adjusted OR (95% CI)	Adjusted *p*-value
Dog age (per 1 year older)	1.13 (1.09, 1.18)	<0.001
Breed		<0.001
Border collie	1.99 (1.51, 2.63)	
Mixed breed	0.94 (0.60, 1.46)	
Shetland sheepdog	1.32 (0.83, 2.10)	
Australian shepherd	1.51 (0.97, 2.36)	
Other	REFERENCE	
Acquired w/agility in mind		0.001
No	0.57 (0.41, 0.78)	
Yes	REFERENCE	
Handler medical training/experience		0.022
None of these	REFERENCE	
Veterinarian	0.98 (0.52, 1.86)	
Licensed vet tech	0.62 (0.26, 1.45)	
Veterinary assistant	2.51 (1.39, 4.53)	
Human health care professional	1.17 (0.84, 1.63)	
Dirt surface		0.017
Never competed	REFERENCE	
<6 times per year	1.53 (1.13, 2.06)	
6+ times per year	1.46 (1.04, 2.06)	
Artificial turf surface		<0.001
Never competed	REFERENCE	
<6 times per year	1.07 (0.77, 1.49)	
6+ times per year	1.77 (1.32, 2.37)	
Weave training method		0.002
2 × 2	REFERENCE	
Channel	0.59 (0.44, 0.79)	
Guide wires	0.79 (0.53, 1.17)	
Other	0.67 (0.45, 1.00)	

who learned weaves by the 2 × 2 training method were more likely to report iliopsoas injury history. All other methods of training reported lower risk (ORs between 0.59 and 0.79), with the channel method associated with the lowest risk of injury.

DISCUSSION

This study found several factors associated with increased risk of developing an iliopsoas injury in dogs competing in agility. Border Collies had increased odds of injury, which aligns with previously published data (1, 12, 14). This consistent finding may be related to the breed's high drive and athleticism, which tends to be one of the primary reasons they are chosen for agility. In human athletes, high speed, intense acceleration, and the tendency to override pain and keep performing, puts athletes at increased risk for muscle injury (15). It is possible that these same characteristics, common in the Border Collie breed, may increase their risk of injury. Speed has been postulated to be a cause for increased injury risk in racing greyhounds as well (16).

Even after adjusting for breed, dogs had a decreased risk for iliopsoas injury if they were not acquired specifically for participation in agility competition, compared to those dogs acquired with the intent to participate in agility. This association may, once again, reflect the greater injury risk among dogs of breeds with higher drive, faster speed, and greater athleticism that are sought by handlers acquiring a dog specifically for agility. It may also be due to handlers who have acquired a dog specifically for agility being more proactive in seeking veterinary care for injury. It is possible that handlers of dogs who were acquired specifically for agility may be more astute in detecting minor changes in their dog's gait or performance, leading to more frequent suspicion and diagnosis of iliopsoas injury. A similar finding was suggested by the Spinella et al. study, where Border Collie owners, and those that participated in agility, sought veterinary care sooner after injury than the other breeds represented (9). While one might assume that dogs acquired with the intent to participate in agility may have increased intensity of training and competition, thereby increasing injury risk, other variables associated with frequency of training and competition did not appear to increase risk of iliopsoas injury in this survey.

Counter to our original hypotheses, only one training factor, the weave obstacle training method, was associated with iliopsoas injury in the final model. There are a variety of methods for training dogs to weave through the weave poles, but in this study the 2 × 2 weave training method was associated with increased iliopsoas injury risk compared to other methods. It is unknown why the 2 × 2 weave training method was associated with increased risk of iliopsoas injury. A recent study described the types of gait patterns dogs use while performing the weave obstacle, but the biomechanical effects on the body have not been evaluated (17). It is unknown if the weave training methods influence the preferred gait pattern through the weave poles, or how the training methods differ in biomechanical effect on the body. It is possible that the 2 × 2 training method requires greater repetitions, or has increased forces on the body, thereby increasing the risk of a repetitive stress iliopsoas injury. It is also possible that the 2 × 2 training method is not directly correlated with iliopsoas injury, but that the dogs of handlers who are choosing the 2 × 2 training method are at increased injury risk due to other influences not evaluated in this survey. Anecdotally, age of initiation of training on various obstacles is frequently thought to be related to risk for injury. However, age of starting various obstacle training was not associated with risk of iliopsoas injury in the final model. Unlike many of the demographic variables, most of the training factors are potentially modifiable, so further evaluation in prospective studies is warranted.

Based on this survey data, competition factors did not influence injury risk as much as initially hypothesized. The number of trial weekends, days of competition per weekend, and number of runs per competition day were not significantly associated with an increased risk of iliopsoas injury, indicating that competition schedule alone may not significantly contribute to iliopsoas injury risk. In the human sports medicine literature, competition frequency and number of games played are only two of many variables that influence total workload for an athlete, which has been shown to be directly related to risk of musculoskeletal injury (18–20). In addition to session frequency, factors such as distance, duration, repetitions, power output, heart rate, and exertion all contribute to external and internal load measures (18–20). It is also established that there are other variables such as psychological stresses, travel, level of fitness, as well as metabolic, hormonal and genetic factors that all contribute to overall load (18–20). A better understanding of competition factors and physiologic variables that contribute to a canine athlete's workload is necessary to determine the relationship with musculoskeletal injury risk.

Of the competition variables, competition surface was associated with risk of iliopsoas injury. Canine athletes competing more frequently on dirt or artificial turf were more likely to have experienced an iliopsoas injury. Anecdotally, many agility competitors prefer dirt or artificial turf due to perceived lower risk of injury from slipping. However, artificial turf varies widely in composition, which can affect the surface properties and traction creating documented alterations in ankle and knee kinematics and kinetics in human athletes (21). Composition and quality of dirt, as well as maintenance of the surface during competitions, also vary widely. Evaluation of surfaces and their impacts on hind limb kinematics has been explored in racing greyhounds, but has not been specifically explored in agility dogs or in relation to injury risk (22). The association between iliopsoas injury risk and surface may be related to the footing itself, or may be correlated with higher speeds in these competition settings. It should be noted that this finding is specific to competition surface and does not account for running surfaces used during training. It is possible that athletes have a higher level of intensity or speed during competition, making the impacts of surface more significant, but this possibility cannot be evaluated with the data from this survey.

Jumping has frequently been suggested as a possible cause of injury for agility athletes, and hesitancy to jump is often one of the first symptoms described after an iliopsoas injury (23–28). Iliopsoas injury has been postulated to result from microtrauma from repetitive jumping, but jumping frequency (based on number of runs per day), age at which jump training was started, and the heights of jumps were not associated with odds of iliopsoas injury in this study. The evaluation the biomechanics of the iliopsoas muscle during agility competition and training activities may reveal additional information about iliopsoas function and injury.

It should be noted that handlers reported that a non-veterinary professional was primarily responsible for treatment decisions in a large percentage of cases. This may reflect increased access to these professionals by the agility community, as well as responsiveness of these professionals to injury concerns. It is important for veterinary professionals to recognize the frequency at which sports medicine treatment decisions (and likely also diagnoses) are being made by other caregivers, as this highlights a potential lack of veterinary involvement in the early stages of injury. This disparity also presents an opportunity for education and growth within veterinary practice to better serve this subset of patients.

While this survey was unable to evaluate precise treatment protocols for iliopsoas injuries due to the lack of acquisition of veterinary medical records, owner-reported treatment for dogs with iliopsoas injury was consistent with current recommendations including rest, pharmaceutical management, and rehabilitation (8, 29). In this survey, many handlers reported using formal rehabilitation therapy and/or in-home rehabilitation as part of their dog's treatment protocol. Rehabilitation is inherently diverse, not only across patients and conditions, but also across practitioners. While we can say that most of the handlers sought rehabilitation as part of their therapeutic plan, details on modalities, duration, frequency, and benefit were not included in this survey. With iliopsoas injury being a common injury reported in the agility population, further evaluation of the effectiveness of rehabilitation techniques, timing, and duration are needed to develop the most appropriate therapeutic plans for patients with the diagnosis of iliopsoas injury.

Some information on recurrence of iliopsoas injury, recovery from injury and return to agility can be inferred from this survey, though not without significant limitations. In this study, 36% of dogs reported a history of multiple iliopsoas strains. Once a muscle or tendon is injured it is more prone to repeat injury or chronic conditions secondary to long-term repetitive overuse/guarding, intermittent inflammation, and repeat micro-injury (5, 15, 30). One study evaluated musculoskeletal ultrasound in agility dogs with iliopsoas injury and reported evidence of both acute and chronic inflammation within the same patient in 62.8% of cases, consistent with repeat micro-injury (5). With regards to iliopsoas injury recovery, this survey found that 56% of dogs were able to return to competition within 3 months, consistent with a median of 91 days to full recovery reported by Spinella et al. (9). The remainder of dogs had a more prolonged convalescence, with 24% returning in

4–6 months, 14% being out of agility for longer than 6 months, and 6% officially retiring. Iliopsoas injuries can be primary, or can occur secondary to orthopedic and neurologic conditions. Underlying orthopedic or neurologic conditions can cause a change in the gait patterning in order to protect the affected joint or region, often by limiting range of motion and relying heavily on muscles like the iliopsoas for stability and compensation (5). It is possible that dogs with secondary iliopsoas injuries could have contributed to the cases with longer recovery times due to the effect of the underlying condition. The nuances of both acute and chronic iliopsoas injury, existence of comorbidities, degree of severity and tendon involvement, and variety in management approaches, make predicting an athlete's ability to return to sport challenging and warrants further exploration.

The results of this study should be interpreted with the understanding that there are significant inherent limitations in a retrospective, owner/handler reported survey, including difficulty in injury recall, self-selection bias, and lack of confirmatory veterinary diagnosis. Participant recall may affect survey outcomes, however, self-reporting and parental reporting in humans has shown good accuracy, especially for major injuries (31–33). It has been established that those who self-select for a survey when it evaluates a topic they care about personally, tend to provide more complete and higher quality data when compared to randomly selected participants, potentially minimizing self-selection bias (34). Agility dog handlers demonstrate a high interest level and commitment to the health of their dogs, as indicated by the 4,197 respondents to this survey, which represents the largest participation in this type of study to date. One of the most substantial limitations of this survey is the lack of access to veterinary records and diagnostics performed. Without the veterinary records it is unknown how the iliopsoas injury was diagnosed, and whether a definitive diagnosis was made. Diagnosis of iliopsoas injuries can be challenging, and presumptive diagnosis is often based on physical examination alone. It is unknown how many of the reported cases had advanced imaging, such as musculoskeletal ultrasound or magnetic resonance imaging (MRI) for confirmation, versus presumptive, and possible inaccurate, diagnosis. Another limitation of these data is the ability to assess certain outcomes due to confounding factors. Some outcomes, such as time to return to competition by those treated by veterinarians / veterinary specialists vs. non-veterinarians, are likely heavily confounded by injury severity (e.g., dogs with more significant injuries were more likely to be treated by a veterinary professional). Focused, prospective studies would allow for improved characterization of iliopsoas injuries and resolution of many of the limitations inherent in this survey.

In conclusion, this survey provides insight into possible risk factors associated with iliopsoas injuries, but also indicates a significant need for studies on pathophysiology of iliopsoas injuries in sporting dogs, as well as best treatment strategies. Further exploration into the relationship of iliopsoas injuries and common comorbidities, the impact of footing on kinematics and injuries in agility courses, as well as weave pole training techniques, is warranted based on these results to help improve the safety of agility as a sport and also better manage one of the most commonly reported injuries. Some of the final risk factors cannot be modified (breed, intended use and handler profession), but can be taken into consideration for injury prevention strategies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Ethical review and approval was not required for the animal study because The Ohio State University Office of Responsible Research Practices determined the project was exempt from IRB review because it was an owner-based internet survey and the information was recorded without direct or indirect identifiers. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

LF and JR participated in data evaluation and writing the manuscript. AP and NK assisted in study design, data collection, data evaluation, and writing the manuscript. AS participated in study design, statistical analysis, and writing the manuscript. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.930450/full#supplementary-material

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Changes in Ground Reaction Forces and Center of Pressure Parameters of Paws When Wearing Dog Boots in Dogs

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Dog boots are commonly used as protective footwear against snow, ice, hot sand, road salt, and paw injury. Only a few studies exist in veterinary medicine that capture the impact of dog boot replacements, such as bandages, on ground reaction forces (GRF) in dogs. To our knowledge, no studies have investigated the effect of dog boots on the center of pressure (COP) in dogs. This study investigated changes in the GRF of the whole limb and selected COP parameters of the paws while wearing dog boots in five Labrador Retrievers. After habituation, data were collected by walking and trotting dogs over a pressure platform without boots (control measurement) and under five different test conditions (wearing boots on all limbs, boots on both front limbs, boots on both hind limbs, one boot on the left front limb, and one boot on the right hind limb). The most prominent change was detectable when one boot was worn on the left front limb, with a decrease of peak vertical force (PFz%) in the left front limb at trot which led to a significant difference between both front limbs and a significant increase of PFz (%) in the right hind limb. Additionally, in both tempi, the vertical impulse (IFz%) showed significant differences between the front limbs; in trot, there was also an increase in the right front limb compared with the control. Furthermore, some significant changes in COP parameters were detected; for instance, all test conditions showed a significant increase in COP area (%) at the right front limb during walking compared to the control. Therefore, our results show that wearing the tested dog boots in different constellations seems to have an impact on GRF and some COP parameters.

Keywords: dog, boots, gait analysis, center of pressure, ground reaction forces

INTRODUCTION

Dog paws are exposed to great stress depending on the animal's use and habitat. They have functional footpads on each of the four weight-bearing toes and a central pad centrally located in the area of the distal metapodium. These hairless, heavily keratinized pads with subcutaneous fat pads have a cushioning effect and are exposed to friction. Contextual separation of pads, such as ulcers, penetrating wounds, abrasions, and chemical or thermal injuries are quite common and often need to be treated surgically or with bandages (1). Injuries to the paws of working and sporting dogs are among the most common (2–4). Dog boots can fulfill a protective function and reduce the number of paw injuries (5). As these are worn for longer periods of time, it is important to ensure the physiological loading of the extremities during the gait cycle. In rehabilitation, especially in the case of neurodegenerative diseases such as degenerative myelopathy, a chronic progressive nerve demyelination that can lead to paraparesis of the hindquarters, paw boots can be used for abrasion protection in addition to physiotherapeutic measures such as training on an underwater treadmill and passive movement exercises (6). Since dog boots are frequently used in everyday life, it is important to understand their influence on dog gait and load distribution.

Several methods are applicable for studying motion sequences. One of them is the measurement of the so-called ground reaction forces, where participants walk and trot over force (7, 8) or pressure plates (9, 10). Force plates directly measure the acting forces in newtons (N), and these generated forces describe the summation of those that act on the limbs during the stance phase, and are divided into vertical, craniocaudal, and mediolateral forces. Pressure plates are used to determine the pressure in Newton/cm². From the pressure data obtained, the acting forces can then be calculated by multiplication of the used area and expressed in Newton, however, only those forces acting in the vertical direction are recorded by pressure measuring plates. Because vertical forces have the largest amplitude (11) they are most frequently used in research and both systems can be used to describe GRF in sound and orthopedically diseased dogs.

In addition to the evaluation of GRF, these gait measurement systems also allow a description of the pressure distribution within the paw as well as the measurement of the center of pressure (COP). The COP describes the point at which the current GRF vector acts and can be described for the whole body as well as for the limbs. If observed during walking or standing (statokinesiogram), a constant change in its position over time creates a COP path. Its course can be described by different COP parameters, such as craniocaudal and mediolateral COP excursions, the path length, velocity as well as the COP area. Measurements of the COP can be used to describe biomechanical adaptations in response to neurological (12) and orthopedic (13, 14) conditions in humans. In veterinary medicine, it has been shown in dogs that the COP can be successfully used to investigate dogs with neurological disorders (15), to detect lameness and describe paw dynamics (16–19). Using static posturography Manera et al. (16) found out that in lame dogs COP parameters were altered in the statokinesiogram and stabilogram. Also Carillo et al. (17) used these methods in a sample of dogs with elbow dysplasia and cranial cruciate ligament rupture, demonstrating a higher COP sway, or "instability," in lame dogs. Lopez et al. (18) used the limb center of pressure to examine if differences between lame and non-lame limbs in dogs with elbow dysplasia were detectable. The results showed, among other things, that due to a shortened swing phase, the limb COP is shortened and cranialized in the lame limb if compared to the non-lame limb. In a recent study, COP data were collected for all four limbs in 24 dogs with cubarthrosis and 19 with coxarthrosis, then compared with 20 orthopedically healthy dogs. Dogs with cubarthrosis showed an increase in craniocaudal COP excursion (%) of the lame limb and an increase in mediolateral COP excursion (%) of the ipsilateral hind limbs. Furthermore, the COP area (%) increased in both the hind limbs. The main change observed in the coxarthrosis group was an increase in the mediolateral COP excursion (%) and COP area (%) in both hind limbs (19).

In human medicine, the effect of different types of footwear on GRF has been successfully investigated. For example, a recent study investigated the GRF during barefoot walking and wearing of sandals, flip-flops, and trainers in 10 men with no history of distal extremity orthopedic disorders using a force plate. The investigation showed a significantly lower stance phase duration when barefoot compared to all types of shoes studied. Furthermore, there was a flatter increase in the loading rate of the 1st peak vertical GRF of the trainers compared to when barefoot, or wearing sandals and flip-flops. The authors concluded that this was due to the thicker and cushioned sole of sports shoes (20).

In another human medical study, in which special pressure sensors were attached to the plantar foot surface of the subjects or in the shoe insoles, a significant difference was detected between barefoot and shoe-wearing subjects in the measured plantar pressure and the pressure contact area. For instance, compared with people wearing shoes, a higher mean pressure and smaller contact area with the ground was measured in the area of the heel when wearing no shoes (21).

In contrast to human medicine, in veterinary research, only a few studies have addressed special devices on dog paws. A recent study investigated the effect of dog boots on GRF by mimicking paw boots with ethylene vinyl acetate pads attached to all paws of six beagles. After a short familiarization period, they were trotted over a force plate. No significant differences in stance phase duration, vertical impulse, and maximum vertical force were found between the measurements with and without dog boots. However, there was a greater increase in the force-time curve to PFz (peak vertical instantaneous loading rate) in shod dogs ($P < 0.05$). The authors concluded that dog boots can definitely fulfill a protective function against environmental influences; however, a variance in the load when wearing dog boots can possibly result in overstressing of the surrounding tissue (5).

In addition to the successful use of pressure plates to measure gait analysis in both healthy and lame dogs and cats (17, 22–24) and objective measurement of the therapeutic success after surgical interventions (25, 26), the measurement of the effectiveness of canine paw devices on GRF, such as ToeGrips® (27, 28), has been used in veterinary medicine. In both ToeGrips® studies, rubber rings were attached to the claws of the weight-bearing toes of orthopedically healthy dogs and the dogs were then walked over a pressure plate after a short acclimatization period. In the first study, there was a significant reduction in PFz in both hind limbs; in the second study, there was only a tendency to be detected. Similarly, the first study measured the prolongation of SPD in all limbs and reported an increase in IFz in both front limbs and the right hind limb. In the second study, there was a reduction seen in IFz for both hind limbs and no significant change was observed in SPD.

No study to date has investigated the effects of dog boots on GRF. This study was carried out using commercially available dog boots[1].

The hypothesis of this study was that despite previous habituation, wearing dog boots on one or more limbs leads to detectable changes in ground reaction forces and selected COP parameters in dogs' limbs.

MATERIALS AND METHODS

Ethics

All measured data were obtained from voluntary sound participants using the same standardized measurement procedure. All measurements were discussed and approved by the Institutional Ethics and Animal Welfare Committee in accordance with the Good Scientific Practice guidelines and national legislation (ETK-103/06/2019).

Dogs and Inclusion Criteria

This paper is an extract from a diploma thesis (29), in which the ground reaction forces of five sound Labrador Retrievers were measured. All dogs were female with a mean age of 4.6 ± 2.3 years and a mean body mass of 26.27 ± 3.1 kg.

Each dog underwent an orthopedic and neurological examination according to Baumgartner (30) at the facilities of the Section for Physical Therapy and Rehabilitation of the University of Veterinary Medicine Vienna to rule out an undiagnosed musculoskeletal disorder. Only dogs with unremarkable orthopedic and neurological examinations, with measured limb loading within the norm (symmetry indices SI <3 %, see below), were included in the study.

Pawz® Rubber Dog Boots

The used dog boots[1] are paw-protection boots that are available in seven sizes and made out of rubber. According to the manufacturer's instructions, shoes were fitted by measuring the distance from the most caudal point of the metacarpal or metatarsal pad to the tip of the longest claw. **Figure 1** shows the used large dog boots.

Equipment

The pressure plate used (FDM Type 2, Zebris Medical GmbH, Allgäu, Germany) measured 203 × 54.2 cm and is able to detect the pressure of the dog's paws using 15,360 piezoelectric sensors at a sampling rate of 100 Hz. In order to ensure unhindered movement of the dog and handler, the pressure plate was surrounded by chipboard and a plain area was prepared and covered with a 1 mm thick, black, non-slip rubber mat, made out of polyvinylchlorid. To assign the measured values to the correct limb of the dog during data evaluation, each measurement was filmed with a Panasonic camera (model NV-MX500).

Measurement Procedure

To participate in this study, all the participants were required to attend the facility twice. At the first appointment, orthopedic and neurological examinations were performed. Then, the dog and owner were given time to familiarize themselves with the movement analysis laboratory and the pressure measurement plate. The procedure was explained, and a written declaration of consent to participate in the study was obtained.

Subsequently, the first GRF measurement was performed. Each dog walked and trotted over a pressure plate without booting. For each measurement, the dog was walked/trotted over the pressure plate until a minimum of 5 valid steps were collected. Only steps during which the dog carried its head straight and walked at a steady pace were considered valid. The difference in velocity at which the dogs crossed the plate should be within a range of ±0.3 m/s at a walk (31), a maximum of 0.5 m/s at a trot (32) and an acceleration of ±0.5 m/s^2.

This procedure was followed for all the subsequent measurements. Symmetry indices (SI) were calculated as described below (see the investigated parameters) to determine whether the dog met all inclusion criteria.

The owner of each dog received four boots of appropriate size. The dogs were then given at least 1 week to become accustomed to wearing the boots in their everyday environment. The owners were instructed to train their dogs under all conditions described below that they would be facing during the subsequent measurements. The dog should wear the boots according to each of the planned measurement conditions for a few minutes, but no longer than 15 min at a time, over the course of a week.

On the day of the actual trials, six measurements were performed during walking and trotting. First, another measurement without boots was performed to ensure that the participant still met the inclusion criterion of SI <3%. The results of these measurements also served as controls for all test conditions.

These test conditions consisted of five different combinations of the number and placement of the worn boots on

- all four limbs
- both front limbs
- both hind limbs
- the left front limb
- the right hind limb

To prevent falsification due to a habituation effect, measurements for the five test conditions were conducted in a randomized order for each animal. The participants were always given a 5–10 min long break, during which they were accustomed to the condition of the following measurement. All data were analyzed using Pressure Analyzer 4.3.2.0 software (Michael Schwanda, Königstetten, Austria) and then exported to Microsoft® Excel® 2016.

Investigated Parameters

GRF Parameters

The peak vertical force (PFz, N) and vertical impulse (IFz, Ns) of each limb were normalized and given as a percentage of the total force [PFz (%), IFz (%)]. The formula is given here based on an

[1] Pawz Rubber dog boots. https://www.pawzdogboots.com/pawz-boots/ (accessed February 10, 2021).

FIGURE 1 | The tested dog boots in size "large" (see text footnote 1).

example for the calculation of PFz of the left front limbs:

$$PF_{zFL}\ (\%) = 100\ x\ \frac{(PFzFL)}{(PFzFL + PFzFR + PFzHR + PFzHL)} \quad (1)$$

Where $PF_{zFL/FR}$ = maximal vertical force front left/front right and $PF_{zHR/HL}$ maximal vertical force hind left/hind right.

For both parameters, a symmetry index was calculated to describe the percent degree of deviation from symmetry in the front and hind limbs (10). The formula is given here based on an example for the calculation of IFz modified from Budsberg et al. (33):

$$\text{SI IFz}\ (\%) = abs\ x \left(\frac{(IFzl - IFzr)}{(IFzl + IFzr)} \right) x\ 100 \quad (2)$$

Where SI_{IFz} = symmetry index of the vertical impulse of a limb pair, IFz_l = Vertical impulse of the left forelimb or hindlimb, $lFz_{r=}$ vertical impulse of the right forelimb or hindlimb, abs = absolute.

The stand phase duration (SPD) was further investigated. It describes the period of time during which the paw contacts the ground and is given as a percentage of the total SPD of all four legs. The other parameters under investigation were speed (m/s), stride length (m), and paw contact area (cm^2).

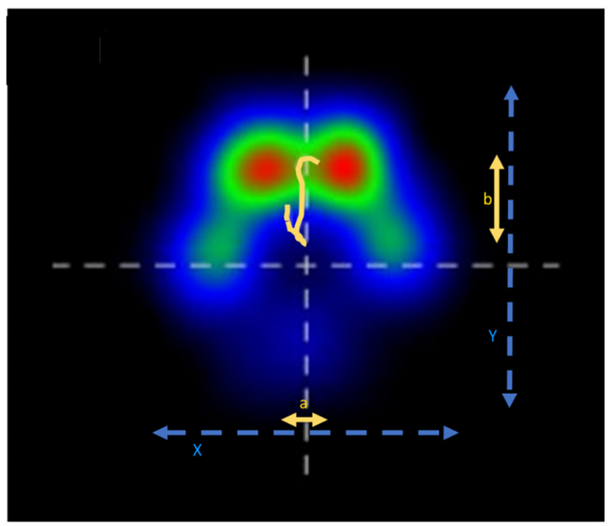

FIGURE 2 | Paw contact area and COP path, a: medio-lateral COP displacement, b: cranio-caudal COP displacement, X: maximum width of paw contact area, Y: maximum length of paw contact area.

COP Parameters

The center of pressure (COP) describes the point at which the current GRF vector acts. If it is observed during walking, a constant change in its position during contact with the ground creates a COP path (19). As shown in **Figure 2**, the mediolateral and craniocaudal COP displacements represent the difference between the maximum positive and negative excursions along the craniocaudal and mediolateral axes. They were expressed as a percentage of the maximum width or length of the paw contact area. The COP area, which includes all points of the COP, was normalized to the paw contact area and expressed as a percentage using the following formula:

$$\text{Area (\%)} = 100/\text{mean A} \times \text{COP area} \quad (3)$$

Where A = mean paw contact area of a leg in mm^2 and COP area = COP area of the respective leg in mm^2.

Statistical Analysis

All the parameters were evaluated using a linear mixed model. The Shapiro–Wilk test was used to check the assumption of a normal distribution of the data. Different conditions and limbs were included as factors in the model. *Post-hoc* testing with Sidak's alpha error correction was performed to compare the control measurements under different conditions. Analyses were performed using IBM SPSS v24 software. For each comparison, $P \leq 0.05$ was considered significant.

RESULTS

The stride length (m) and velocity (m/s) showed no significant changes between each test condition and the control during walking and trotting.

An overview of all mean ± standard deviation, where significant differences between the control and test conditions are marked with superscript symbols, is given in **Tables 1**–**6**. **Figure 3** shows a visualized overview of all significantly changed parameters.

Control—No Dog Boots

Both PFz (%) and IFz (%) showed significantly higher values for the front limbs than for the hind limbs in both gaits ($P = 0.000$). A significant difference between the front and hind limb pairs was observed in the SI PFz (%) during trotting (higher in the hind limbs), with a *P*-value of 0.015. At trot, SPD (%) was significantly longer in the front limbs than in the ipsilateral (left front—left hind $P = 0.022$, right front—right hind $P = 0.038$) and contralateral hind limbs (left front—right hind $P = 0.038$, right front—left hind $P = 0.019$). In both gaits, the paw contact area (cm^2) was significantly greater in the front than in the hind limbs (walk: left front—left hind $P = 0.031$, right front—right hind $P = 0.011$, left front—right hind $P = 0.015$, right front—left hind $P = 0.024$; trot: left front—left hind $P = 0.002$, right front—right hind $P = 0.001$, left front—right hind $P = 0.000$, right front—left hind $P = 0.004$). The mediolateral COP displacement (%) was significantly lower in the left front limb than in both hind limbs during walking (left front—left hind $P = 0.046$, left front—right hind $P = 0.027$). The COP area (%) did not show any significant difference in either gait when comparing individual limbs within the condition (**Table 1**).

Boots on All Four Limbs

Wearing boots on all four limbs resulted in a significant increase in COP area (%) during walking in the right ($P = 0.047$) and left front limbs ($P = 0.023$) compared with the control. Similarly, a significant increase in the mediolateral COP displacement (%)

TABLE 1 | Mean ± standard deviation of all parameters for the condition "no dog boots."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	30.45 ± 1.81*,‡	1.12 ± 0.96	31.64 ± 0.46*,‡	1.19 ± 1.13	0.47 ± 0.08	0.8 ± 0.06	44.27 ± 2.63*,‡	1.17 ± 0.23	24.81 ± 2.96	4.34 ± 0.58*,‡	0.83 ± 0.15
	RF	30.18 ± 1.28*,‡		32.25 ± 0.48*,‡		0.48 ± 0.08	0.81 ± 0.07	44.78 ± 2.84*,‡	1.14 ± 0.23	24.21 ± 3.32	5.21 ± 0.68	0.83 ± 0.14
	LH	19.77 ± 1.4	0.52 ± 0.25	17.96 ± 0.	0.82 ± 0.45	0.44 ± 0.08	0.81 ± 0.06	38.19 ± 4.26	1.15 ± 0.23	21.44 ± 2.43	5.28 ± 0.67	0.9 ± 0.14
	RH	19.61 ± 1.63		18.15 ± 0.26		0.44 ± 0.08	0.81 ± 0.07	37.63 ± 3.83	1.13 ± 0.22	22.37 ± 2.3	6.35 ± 1.38	0.92 ± 0.27
Trot	LF	31.26 ± 0.47*,‡	0.54 ± 0.39*	32.47 ± 0.59*,‡	1.24 ± 0.67	0.24 ± 0.02*,‡	1.05 ± 0.04	51.59 ± 1.43*,‡	2.21 ± 0.18	19.79 ± 1.63	4.18 ± 1.03	0.61 ± 0.18
	RF	31.2 ± 0.64*,‡		32.07 ± 0.39*,‡		0.24 ± 0.02*,‡	1.06 ± 0.05	50.93 ± 2.45*,‡	2.24 ± 0.13	20.65 ± 1.81	4.3 ± 0.54	0.66 ± 0.16
	LH	18.89 ± 0.84	1.69 ± 0.48	17.68 ± 0.54	1.61 ± 0.99	0.21 ± 0.02	0.82 ± 0.45	43.80 ± 2.98	2.23 ± 0.19	19.02 ± 2.32	4.71 ± 1.63	0.59 ± 0.26
	RH	18.66 ± 0.23		17.78 ± 0.3		0.21 ± 0.02	1.03 ± 0.02	42.73 ± 2.41	2.16 ± 0.19	20.25 ± 2.25	5.16 ± 1.37	0.68 ± 0.19

*Indicate a significant difference between the ipsilateral limb pairs; ‡ between diagonal limb pairs.

TABLE 2 | Mean ± standard deviation of all parameters for the condition "boots on all four limbs."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	29.78 ± 1.66*,‡	1.12 ± 1.36	31.73 ± 1.06*,‡	1.66 ± 1.41	0.51 ± 0.05	0.8 ± 0.05	44.36 ± 2.57*,‡	1.08 ± 0.13	26.47 ± 4.75	5.65 ± 0.85$^{\#}$	1.12 ± 0.18$^{\#}$
	RF	29.3 ± 1.42*,‡		31.99 ± 0.79*,‡		0.52 ± 0.04	0.81 ± 0.06	44.68 ± 2.2*,‡	1.07 ± 0.12	26.02 ± 5.82	5.72 ± 0.95	1.13 ± 0.23$^{\#}$
	LH	19.77 ± 1.4	0.86 ± 0.81	18.1 ± 0.59	1.13 ± 0.67	0.47 ± 0.04	0.8 ± 0.04	37.58 ± 4.42	1.08 ± 0.11	20.34 ± 4.04	5.94 ± 0.62	0.83 ± 0.23
	RH	20.29 ± 1.48		18.18 ± 0.69		0.47 ± 0.03	0.8 ± 0.04	37.78 ± 3.69	1.05 ± 0.1	21.32 ± 3.62	6.09 ± 1.34	0.93 ± 0.21
Trot	LF	31.26 ± 0.47*,‡	1.03 ± 0.48	32.56 ± 0.94*,‡	1.2 ± 1.66	0.26 ± 0.03*,‡	1.01 ± 0.04	50.35 ± 2.34*,‡	2.04 ± 0.27	20.45 ± 1.2	3.75 ± 0.47	0.54 ± 0.12
	RF	31.2 ± 0.64*,‡		32.49 ± 0.23*‡		0.26 ± 0.02*,‡	1.01 ± 0.05	50.35 ± 3.02*,‡	2.09 ± 0.25	20.79 ± 2.04	4.18 ± 1.03	0.68 ± 0.27
	LH	18.89 ± 0.84	0.98 ± 1.29	17.37 ± 0.79	1.63 ± 1.05	0.21 ± 0.02	1.02 ± 0.06	41.73 ± 4.42	2.07 ± 0.27	16.77 ± 4.22	4.16 ± 1.1	0.47 ± 0.19
	RH	18.66 ± 0.23		17.58 ± 0.15		0.22 ± 0.02	1.01 ± 0.07	41.58 ± 3.7	2.04 ± 0.29	17.1 ± 4.26	5.11 ± 1.57	0.65 ± 0.08

**Indicate a significant difference between the ipsilateral limb pairs; ‡ between diagonal limb pairs; # differences between the control and the boot wearing conditions.*

TABLE 3 | Mean ± standard deviation of all parameters for the condition "boots on both front limbs."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	30.09 ± 1.66*,‡	1.23 ± 0.68	31.22 ± 0.73*,‡	1.31 ± 0.89	0.49 ± 0.08	0.79 ± 0.06	44.61 ± 2.75‡	1.09 ± 0.22	25.3 ± 4.92	4.99 ± 0.83	0.98 ± 0.23
	RF	29.91 ± 1.15*,‡		31.94 ± 0.77*,‡		0.5 ± 0.08	0.79 ± 0.06	44.74 ± 3.46*	1.09 ± 0.25	25.59 ± 4.73	5.39 ± 0.99	1.03 ± 0.15$^{\#}$
	LH	20.19 ± 1.47	1.53 ± 1.81	18.48 ± 0.79	0.59 ± 0.52	0.46 ± 0.07	0.79 ± 0.06	39.09 ± 4.94	1.09 ± 0.23	21.4 ± 4.35	5.42 ± 0.62	0.84 ± 0.22
	RH	19.81 ± 1.38		18.36 ± 0.53		0.46 ± 0.08	0.79 ± 0.06	38.14 ± 3.88	1.08 ± 0.25	21.43 ± 3.82	5.87 ± 1.4	0.92 ± 0.23
Trot	LF	30.81 ± 0.62*,‡	0.58 ± 0.40	32.22 ± 1.03*,‡	1.25 ± 0.98	0.25 ± 0.02*,‡	0.99 ± 0.06	50.03 ± 1.96*,‡	2.05 ± 0.31	20.57 ± 2.01	4.1 ± 0.94	0.6 ± 0.22
	RF	30.88 ± 0.7*,‡		32.15 ± 0.51*,‡		0.26 ± 0.03*,‡	1.01 ± 0.07	50.2 ± 2.85*,‡	2.08 ± 0.28	20.97 ± 2.83	3.99 ± 0.95	0.63 ± 0.22
	LH	19.26 ± 0.84	1.14 ± 1.10	17.87 ± 0.88	1.09 ± 0.97	0.22 ± 0.02	1.0 ± 0.05	43.34 ± 4.59	2.05 ± 0.26	18.1 ± 4.47	4.47 ± 0.93	0.58 ± 0.22
	RH	19.06 ± 0.47		17.76 ± 0.34		0.22 ± 0.02	1.01 ± 0.07	42.58 ± 3.05	2.06 ± 0.32	18.37 ± 3.77	5.79 ± 2.08	0.72 ± 0.11

**Indicate a significant difference between the ipsilateral limb pairs; ‡ between diagonal limb pairs; # differences between the control and the boot wearing conditions.*

TABLE 4 | Mean ± standard deviation of all parameters for the condition "boots on both hind limbs."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	30.35 ± 1.27[*,‡]	1.08 ± 0.98	31.9 ± 1.21[*,‡]	1.10 ± 1.61	0.51 ± 0.09[*,‡]	0.81 ± 0.08	45.26 ± 2.88	1.1 ± 0.28	25.02 ± 3.24	4.91 ± 0.99[†]	0.95 ± 0.22
	RF	30.2 ± 1.11[*,‡]		32.37 ± 0.94[*,‡]		0.52 ± 0.08[*,‡]	0.8 ± 0.07	46.03 ± 3.44	1.1 ± 0.25	24.69 ± 3.34	6.92 ± 1.25[#]	1.18 ± 0.19[#]
	LH	19.85 ± 1.06	1.92 ± 1.24	17.88 ± 0.63	1.51 ± 1.12	0.47 ± 0.08	0.8 ± 0.07	37.49 ± 4.26	1.08 ± 0.24	21.2 ± 4.6	6.1 ± 1.35	0.94 ± 0.25
	RH	19.6 ± 1.32		17.85 ± 0.91		0.47 ± 0.08	0.8 ± 0.08	36.96 ± 4.47	1.1 ± 0.27	21.55 ± 3.46	6.17 ± 1.53	0.95 ± 0.27
Trot	LF	30.95 ± 0.91[*,‡]	0.93 ± 0.96	32.74 ± 1.39[*,‡]	1.75 ± 1.03[*]	0.26 ± 0.03[*,‡]	1.01 ± 0.06	51.56 ± 3.23	2.05 ± 0.21	19.76 ± 2.4	4.55 ± 0.95	0.69 ± 0.26
	RF	30.97 ± 0.59[*,‡]		32.74 ± 0.39[*,‡]		0.26 ± 0.02[*,‡]	0.99 ± 0.03	51.1 ± 3.75	1.95 ± 0.16	20.08 ± 2.6	4.22 ± 1.1	0.67 ± 0.23
	LH	19.14 ± 0.94	1.34 ± 0.86	17.37 ± 0.99	1.16 ± 1.21	0.21 ± 0.02	0.74 ± 0.48	42.02 ± 2.88	1.94 ± 0.15	17.74 ± 4.26	4.72 ± 1.4	0.66 ± 0.28
	RH	18.95 ± 0.35		17.35 ± 0.55		0.22 ± 0.02	1.0 ± 0.05	42.35 ± 3.31	1.98 ± 0.27	17.7 ± 3.19	5.44 ± 0.94	0.68 ± 0.07

**Indicate a significant difference between the ipsilateral limb pairs; † between contralateral limb pairs; ‡ between diagonal limb pairs; # differences between the control and the boot wearing conditions.*

TABLE 5 | Mean ± standard deviation of all parameters for the condition "boots on the left hind limb."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	29.88 ± 1.89[*,‡]	1.86 ± 1.20	30.65 ± 1.02[*,†,‡]	3.84 ± 2.02	0.51 ± 0.06	0.79 ± 0.07	44.03 ± 2.36[*,‡]	1.05 ± 0.16	25.69 ± 4.7	5.3 ± 1.21	1.04 ± 0.21
	RF	30.19 ± 1.47[*,‡]		33.09 ± 0.83[*,‡]		0.54 ± 0.06	0.79 ± 0.05	45.16 ± 2.52[*,‡]	1.03 ± 0.12	24.53 ± 3.97	7.24 ± 2.04	1.27 ± 0.25[*,‡,#]
	LH	20.03 ± 1.69	0.82 ± 0.73	17.96 ± 0.67	1.76 ± 1.09	0.48 ± 0.05	0.79 ± 0.06	38.06 ± 4.32	1.05 ± 0.16	21.37 ± 3.36	5.79 ± 0.67	0.82 ± 0.1
	RH	19.91 ± 1.42		18.3 ± 0.84		0.49 ± 0.05	0.78 ± 0.05	38.25 ± 3.58	1.02 ± 0.12	22.21 ± 2.58	6.1 ± 1.32	0.9 ± 0.23
Trot	LF	30.16 ± 0.69[*,†,‡,#]	2.28 ± 0.62[#]	31.39 ± 0.91[*,†,‡]	2.63 ± 1.57	0.26 ± 0.03	0.99 ± 0.06	49.67 ± 1.91[*,‡]	2.0 ± 0.26	19.21 ± 1.23	4.38 ± 0.51	0.58 ± 0.14
	RF	31.57 ± 0.52[*,‡]		33.09 ± 0.78[*,‡,#]		0.26 ± 0.02[*,‡]	1.02 ± 0.03	51.77 ± 2.58[*,‡]	2.06 ± 0.15	20.02 ± 1.77	4.47 ± 0.91	0.67 ± 0.11
	LH	18.93 ± 0.8	1.60 ± 0.89	17.61 ± 1.06	1.99 ± 0.82	0.22 ± 0.02	1.02 ± 0.03	42.76 ± 3.45	2.05 ± 0.17	17.65 ± 4.05	4.31 ± 1.15	0.6 ± 0.3
	RH	19.35 ± 0.46		17.91 ± 0.35		0.22 ± 0.02	1.0 ± 0.06	43.19 ± 2.92	1.98 ± 0.29	18.15 ± 2.88	5.38 ± 1.68	0.67 ± 0.09

**Indicate a significant difference between the ipsilateral limb pairs; † between contralateral limb pairs; ‡ between diagonal limb pairs; # differences between the control and the boot wearing conditions.*

TABLE 6 | Mean ± standard deviation of all parameters for the condition "boots on right hind limbs."

	Limb	PFz (%)	SI PFz (%)	IFz (%)	SI IFz (%)	SPD (%)	SL (m)	PCA (cm^2)	v (m/s)	COP cran-caud (%)	COP med-lat (%)	COP area (%)
Walk	LF	30.35 ± 1.47*,‡	1.27 ± 0.79	31.92 ± 1.01*,‡	1.97 ± 1.66	0.51 ± 0.09	0.81 ± 0.06	45.18 ± 2.87*,‡	0.92 ± 0.48	25.29 ± 3.79	5.69 ± 1.41	1.08 ± 0.19#
	RF	30.34 ± 0.9*,‡		32.41 ± 1,0*,‡		0.52 ± 0.09	0.81 ± 0.06	45.81 ± 3.34*,‡	0.9 ± 0.52	24.81 ± 3.73	6.79 ± 1.57	1.11 ± 0.23#
	LH	19.42 ± 0.91	1.83 ± 1.23	17.87 ± 0.71	0.94 ± 0.12	0.47 ± 0.08	0.81 ± 0.05	38.19 ± 5.44	0.89 ± 0.44	21.17 ± 3.68	5.7 ± 0.59	0.89 ± 0.13
	RH	19.89 ± 1.4		17.81 ± 0.45		0.47 ± 0.08	0.8 ± 0.06	36.99 ± 4.25	0.9 ± 0.52	21.71 ± 3.79	5.62 ± 1.39	0.87 ± 0.24
Trot	LF	30.93 ± 0.89*,‡	0.97 ± 0.99	32.26 ± 1.25*,‡	1.27 ± 1.48	0.26 ± 0.03*	1.01 ± 0.07	51.37 ± 2.71*,‡	2.04 ± 0.28	20.45 ± 1.63	4.94 ± 2.38	0.78 ± 0.43
	RF	31.16 ± 0.73*,‡		32.53 ± 0.15*,‡		0.26 ± 0.03‡	1.02 ± 0.07	51.48 ± 3.45*,‡	2.09 ± 0.35	19.69 ± 2.13	4.18 ± 1.05	0.57 ± 0.15
	LH	19.06 ± 0.92	1.26 ± 1.05	17.63 ± 0.71	1.61 ± 0.93	0.22 ± 0.02	0.83 ± 0.41	42.95 ± 3.71	2.07 ± 0.35	18.23 ± 4.31	4.49 ± 1.01	0.6 ± 0.23
	RH	18.84 ± 0.53		17.58 ± 0.74		0.22 ± 0.03	0.99 ± 0.06	41.86 ± 3.45	1.96 ± 0.3	17.95 ± 3.53	5.26 ± 2.3	0.68 ± 0.25

*Indicate a significant difference between the ipsilateral limb pairs; ‡ between diagonal limb pairs; # differences between the control and the boot wearing conditions.

during walking in the left front limb compared to the control was detected ($P = 0.025$); however, no significant difference was detected between the left front limb and both hind limbs (**Table 2**).

Boots on Both Front Limbs

During walking, a significant difference in paw contact area (%) was only detected between the right hind and both front limbs (left front $P = 0.018$, right front $P = 0.022$). During walking, the COP area (%) showed a significant increase in the right front limb compared with the control, with a P-value of 0.054. No significant difference in the mediolateral COP displacement (%) was observed between the left front limb and both hind limbs (**Table 3**).

Boots on Both Hind Limbs

When boots were worn on both hind limbs at trot SI IFz (%) decreased in the hind limbs and increased in the front limbs, which led to a significant difference between the front and hind limb pairs ($P = 0.033$). A significant increase in the mediolateral COP displacement (%) in the right front limb was found during walking compared to that in the control ($P = 0.036$), which led to a significant difference between the front limbs in this condition ($P = 0.024$), but not between the left front limb and both hind limbs. Likewise, a significant increase in the right front limb occurred in the COP area (%) compared with the control ($P = 0.012$, **Table 4**).

Boot on the Left Front Limb

A decrease in PFz (%) in the left front limb was found during trotting when wearing a boot on the left front limb compared with the control ($P = 0.022$). This resulted in a significant difference between the front limbs ($P = 0.008$). Furthermore, a significant increase in PFz (%) was observed in the right hind limb ($P = 0.025$). The SI PFz (%) of the front limb pair increased significantly during trot compared with the control ($P = 0.019$). During walking and trotting, IFz (%) showed a significant difference between both front limbs in this condition (walk: $P = 0.004$, trot: $P = 0.014$), with a significant increase in the right front limb compared to the control ($P = 0.041$). At trot, SPD (%) increased in the front legs and showed a significant difference only between the right front limb and both hind limbs ($P = 0.014$) but not in comparison to the controls. The COP area (%) in the right front limb during walking increased significantly in this condition compared to that in the control ($P = 0.013$), resulting in a significant difference between the right front limb and both hind limbs (right front—left hind $P = 0.013$, right front—right hind $P = 0.044$). At both gaits for mediolateral COP displacement (%), no significant difference was observed when comparing the conditions with each other or when comparing the individual limbs within each condition (**Table 5**).

Boot on the Right Hind Limb

At trot, SPD (%) showed only a significant difference between the left hind limb and both front limbs (front left—hind left $P = 0.035$; front right—hind left $P = 0.046$). No significant difference in the mediolateral COP displacement (%) was

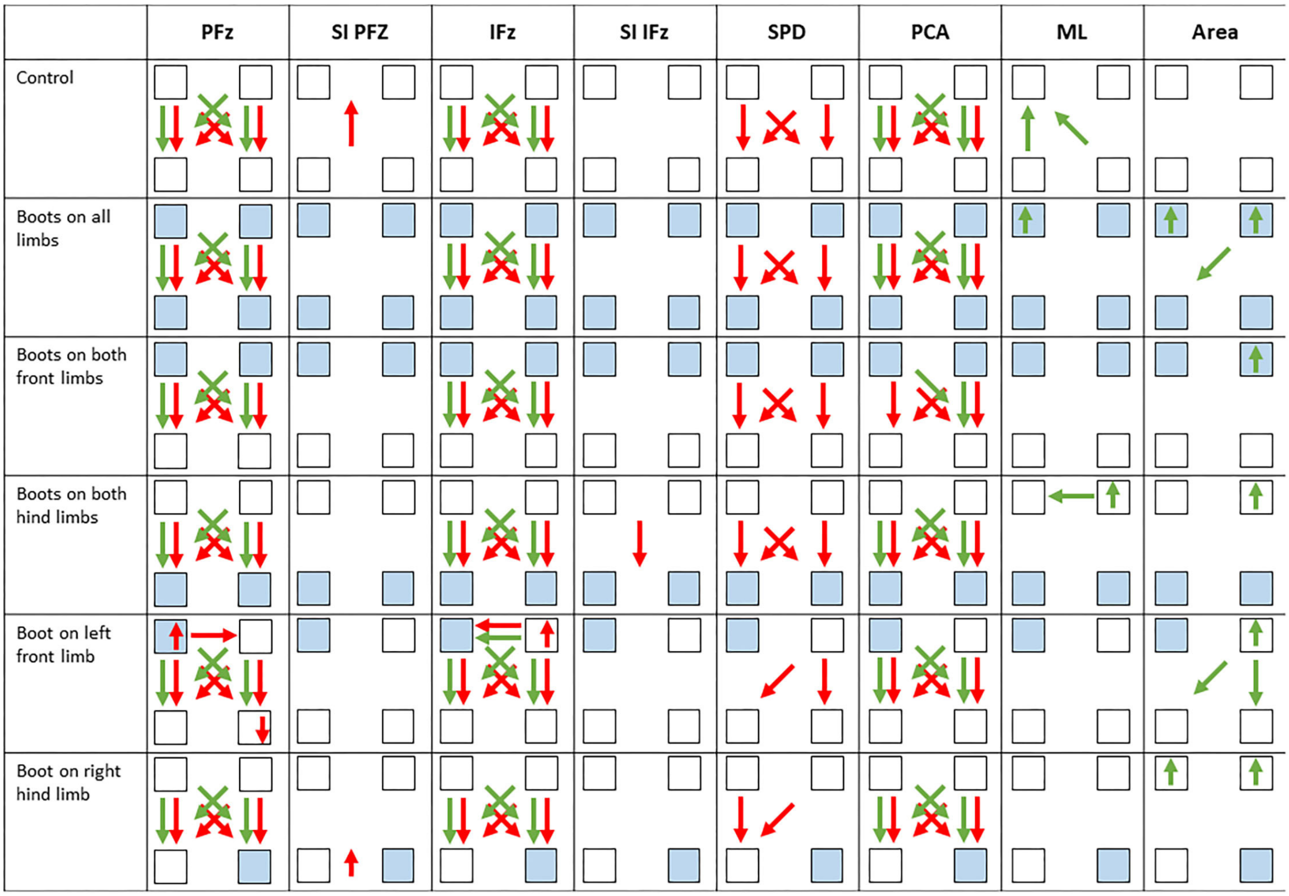

FIGURE 3 | Visualized overview of altered parameters, based on at least five steps/dog per measurement. Data were evaluated using a linear mixed model and *post-hoc* testing with Sidak's alpha error correction. Each square represents a limb where those in blue represent boot-wearing limbs. The arrows between the squares show significant differences between the legs where the green represents walking and red for trotting. The arrowhead points in the direction of the lower value in each case. In case of a significant difference between the control and a test condition, an arrow within or beside the square indicates an increase or decrease of the value. For instance, when a dog boot was worn on the left front limb, PFz (%) at walk showed higher values in both front limbs and a decrease in the left front limb and an increase in the right hind limb compared to the control. Further, a significant difference between both front limbs was observed. PFz, peak vertical force; SI PFz, symmetry index of PFz; IFz, vertical impulse; SI IFz, symmetry index of IFz; SPD, stance phase duration; PCA, paw contact area; ML, medio-lateral COP displacement; area, COP-area.

observed during walking or trotting when comparing the conditions or when comparing the individual limbs within each condition. Wearing a boot on the right hind limb led to a significant increase in the COP area (%) during walking in the left and right front limbs compared to the control, with a *P* -value of 0.050 (left front) and 0.053 (right front) (**Table 6**).

DISCUSSION

Dogs may need to wear paw boots for a wide variety of reasons, whether for sports or for medical purposes. It is therefore important to recognize changes in loading on the dog's legs when they are worn. The hypothesis that wearing the tested boots on single or multiple limbs results in a measurable change in the ground reaction forces of the entire limb, as well as a change in the COP area (%) and craniocaudal and mediolateral COP displacement (%) of the paw in dogs, despite prior habituation, was partially confirmed in this study.

With regard to GRF parameters, wearing a boot on the left forelimb primarily showed an effect indicating a significant redistribution of GRF toward the contralateral front limb and, in the case of PFz (%), also toward the diagonal hind limb. Interestingly, this effect was not observed when a boot was worn on only one hind limb. However, in comparison with the existing literature regarding the compensatory effects of lameness, similarities can certainly be found. For instance, a study in dogs with osteoarthrosis of the elbow joint showed a comparable redistribution of GRF evaluated on a pressure plate (23). Regarding hind lameness, research performed on pressure or force plates provides different results; for example, dogs with orthopedic diseases of one hind limb usually show an increase in GRF in the contralateral limb, and compensations to the front are rarely described (17, 34–36). Accordingly, while wearing a boot on the front limb tends to cause compensation in the dog, wearing it on the hind limb does not seem to cause any interference. This could possibly be due to the fact that the forces acting on the front limbs are generally higher than those acting on the hind limbs (24, 34, 37, 38). However, it appears that the effect no longer occurs once the animal wears the boots on both front limbs.

In comparison with the scarce literature on the subject, some differences appear regarding the ground reaction forces. Shorter and Brown (5) used a force plate evaluation and did not show any differences in PFz and IFz, but these authors performed measurements with shoes on all four paws. In addition, the authors used a two millimeter thick ethylene-vinyl acetate pad attached to the paw with a self-adhesive tape up to the carpus. Because this boot replacement extends further proximally than the tested boots and has a sole, it differs from the boots used in the present study. A recent study that used special devices on all four dog paws (ToeGrips®) observed on a pressure platform a significant decrease in PFz in both hind limbs, as well as an elongation of SPD in all limbs (27). None of the mentioned changes could be detected in this study compared to wearing boots on all four limbs during walking or trotting, which could be due to the different fitting and effect of ToeGrips® in comparison to dog boots. As there were no significant differences in paw contact area (cm^2) between the control and when boots were worn on different limbs, it can be assumed that the tested boots fit so tightly to the paw that no change in paw contact area could be measured. Wearing these boots also had no effect on stride length. As there are a variety of boots for dogs with different profiles and sole thicknesses, further studies comparing different types of boots would be interesting.

However, we were able to record a stronger effect on the evaluated parameters of the COP area. In each of the test conditions, the COP area increased in at least one of the forelimbs and the mediolateral COP (%) of the front limbs was affected only when boots were worn on all four limbs or both hindlimbs. Interestingly, the craniocaudal displacement of the COP (%) did not change under any of the test conditions. Measurement of the COP within the paw is a fairly new method in veterinary medicine to describe biomechanical adaptations and possible compensatory mechanisms that may occur (16, 17, 19). In healthy dogs (19), all evaluated parameters had higher values in the forelimbs than in the hind limbs. This could not be confirmed in the present study for the COP area, in which both limb pairs showed comparable values. Reicher et al. (19) used a heterogeneous dog group consisting of 20 individuals to evaluate healthy dogs. Whether the differences in the results between the studies were due to a different number of subjects or a heterogeneous group composition must be investigated in subsequent studies. Nevertheless, the changes induced by the boots did not coincide with those observed in dogs with coxarthrosis (19). Mediolateral displacement (%) did not increase in the hind limbs, but did in the forelimbs when a boot was worn on one hind limb, a situation reversed in dogs with coxarthrosis. Compared to dogs with cubarthrosis (16, 19), changes in the front limbs could also be observed; however, in the latter, the craniocaudal COP (%) on the contralateral front limb and the COP area (%) of the hind limbs increased, whereas in dogs that wore boots on one or both front limbs, the COP area (%) of the front limbs increased. An increase in COP values is generally interpreted in the literature as a sign of reduced stability (17, 39). Likewise, changes in COP parameters can also be considered in terms of biomechanical adaptations. In dogs with unilateral elbow joint dysplasia, Lopez et al. (18) described that limb COP path in lame limbs is shortened and compared with the contralateral limb cranialized, due to a larger caudal margin (which describes the distance between the most caudal limit of the paw print and the most caudal limit of the limb COP path). The authors explained this by a shortened swing phase and reduced extension, which ultimately leads to incorrect load takeover of the metacarpal pad during landing. Because the caudal margin was not evaluated in our study, further studies should investigate the extent to which this value is influenced by the wearing dog boots. The same authors also describe in their study an increased mediolateral deviation of the COP in the non-lame limb, which was interpreted as a result of an increased pad deformation caused by the increased weight bearing. The results of our study do not show comparable results for this parameter, as no changes in GRFs were observed in those conditions in which mediolateral deviation of the COP was increased. Finally, Lopez et al. detected increased values of COP area in a statokinesiogram, which they interpreted as an indication of increased instability. Also in our study, significant changes of the COP area in the front limb area were shown, which could be interpreted as an indication that the wearing of boots leads to a certain increased instability, even though the dogs have been previously habituated to wearing the boots. A possible explanation could be that sensory stimuli may be partially lost because of the rubber layer between the paw and ground. In humans, sensory input through the sole of the foot influences postural control (40, 41). The absence of plantar cutaneous sensation has also been shown to affect COP parameters when the postural control system is challenged (42).

A limiting factor of this study is the relatively small number of subjects, although this was partially compensated by the use of the same breed. Nevertheless, further studies with more animals, especially different breeds, will be necessary to clarify the effects of the tested boots on GRF and COP. Whether the thickness of the sole, stability of the shoe, and size of the contact area of the shoe with the ground lead to varying results in ground reaction forces as well as COP parameters requires further investigation. In humans, it is assumed that the cushion and thickness of the sole have an impact on the loading rate of peak GRF, being smaller when wearing shoes compared to flip-flops and sandals, and being barefoot (13). In further studies on the topic, the combination "boots on a diagonal limb pair," which was not measured in this work, should also be tested.

In summary, this study found small changes in the GRF between wearing boots and walking without boots, but signs of reduced stability between paw and ground during the stance phase of the front legs, which should be considered when using these dog boots. Furthermore, it should be mentioned that the manufacturer warns against unsupervised use and prolonged wearing of the boots[2]. Whether long-term use will cause deviations in limb loading with further effects on the

[2]Pawz. Pawz Large Size dog boots. https://pawzdogboots.com/product/large-size-rubber-boots/ (accessed February 10, 2021).

orthopedic health of dogs needs to be explored in further studies. It should also be mentioned that paw boots on only one limb are mostly used for medical reasons and therefore only for a limited period of time, for instance, until a wound has healed. The question remains as to whether these deviations in the evaluated parameters while wearing a boot actually have an effect on further orthopedic health issues.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The animal study was reviewed and approved by Ethics and Animal Welfare Committee, University of Veterinary Medicine, Vienna, Austria. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

BR and BBo contributed to the conception and design of the study. BR and BBi performed the measurements and data evaluation. AT performed the statistical analysis. BBi wrote the draft of the paper. BR and BBo wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Nonsurgical Rehabilitation in Dachshunds With T3-L3 Myelopathy: Prognosis and Rates of Recurrence

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Dachshunds are at significant risk of experiencing thoracolumbar intervertebral disk herniation (IVDH) during their lifetimes. Standard of care includes advanced imaging, surgical intervention, and postoperative rehabilitation. Conservative management is commonly recommended for cases where the standard of care is declined, and little is known about the prognosis of treatment with conservative management and rehabilitation (nonsurgical rehabilitation). This retrospective cohort study assessed 12-week functional outcome and recurrence of clinical signs in 40 dachshunds with T3-L3 myelopathy presumed to be due to Hansen's Type I disc herniation, treated with nonsurgical rehabilitation. The overall prognosis was good with 34 of 40 (85.0%, 95% CI 70.2–94.2) dachshunds achieving functional pet status by 12 weeks postinjury. Modified Frankel Score at presentation was significantly ($p < 0.001$) higher in dogs with a positive 12-week outcome compared to dogs that did not recover by 12 weeks. All 27 dogs with motor function at presentation had a positive outcome. Of the 9 dogs exhibiting paraplegia with intact deep nociception at presentation, 7 dogs (77.8%) had achieved a positive outcome by 12 weeks. None of the 4 dogs persistently lacking deep nociception had a positive outcome. Among 27 dogs with a positive outcome for whom follow-up records were available, the 1- and 2-year recurrence rates for T3-L3 myelopathy were 5 and 11%, respectively. Nonsurgical rehabilitation should be considered in dachshunds with mild to moderate T3-L3 myelopathy or in severe cases when advanced imaging and surgical intervention are not possible.

Keywords: rehabilitation, T3-L3 myelopathy, veterinary neurology, acupuncture, nonsurgical, hyperbaric oxygen, IVDH

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INTRODUCTION

Intervertebral disk herniation (IVDH) is a common condition in dogs with a lifetime prevalence of ∼3.5%. The incidence is significantly higher in chondrodysplastic breeds with a 20% lifetime prevalence in the miniature dachshund (1). These injuries most commonly occur in the thoracolumbar (T3-L3) region of the spine (2–4). The current standard of care for T3-L3 myelopathy with severe neurologic signs or refractory pain recommends advanced imaging to identify the level of injury and diagnose the underlying etiology, followed by surgical intervention to address the primary injury to the spinal cord when possible (5). Studies have found that dogs with IVDH that undergo hemilaminectomy have a good prognosis for return to normal function if deep nociception is present prior to surgery (97.7% return to ambulation). If deep nociception is not present prior to surgery the likelihood of return to ambulation decreases (52.1%) (6). Less severe injuries are associated with earlier time to ambulation in the postoperative period (6, 7).

In a review from 2016, rehabilitation was recommended after hemilaminectomy by 64% of board-certified surgeons, and 46% of board-certified neurologists (8). Rehabilitation typically consists of a variety of techniques and modalities including, but not limited to, passive range of motion, therapeutic exercise, underwater treadmill, manual therapy, acupuncture or electroacupuncture, photobiomodulation, transcutaneous electrical nerve stimulation (TENS), neuromuscular electrical stimulation (NMES), pulsed electromagnetic field therapy (PEMF), and hyperbaric oxygen therapy (HBOT) (9–12). A retrospective analysis of postoperative rehabilitation following T3-L3 hemilaminectomy in 2015 found an association between rehabilitation and positive outcomes after surgery (13). Rehabilitation has also been associated with more complete recovery after surgery (14, 15). However, recent prospective studies have had more equivocal results (16, 17).

Due to financial constraints or personal preferences, many owners are unable to pursue the standard of care detailed above. For these patients, medical management is typically recommended. Usually, this includes cage rest, pharmaceutical administration (analgesics, muscle relaxants, and anti-inflammatory medications), and if possible physical rehabilitation. Levine et al. found that in 223 dogs with presumed thoracolumbar IVDH receiving cage rest and medications, 54.4% achieved a successful outcome defined as a significant improvement in neurologic function with no report of recurrence of clinical signs. An additional 14.5% were considered treatment failures, progressing to surgery, or euthanasia. Dogs undergoing conservative management exhibited rates of recurrence similar to surgically treated dogs with thoracolumbar disc herniations. Successful outcomes were found to be associated with the duration of clinical signs at admission. The study did not assess participation in a rehabilitation program as a parameter of conservative management (4).

The first study that described nonsurgical rehabilitation techniques for T3-L3 myelopathy in dogs was published by Jadeson in 1961. Eighty-two dogs were treated for their myelopathy with conventional treatment including nursing care, muscle relaxants, steroids, antibiotics, vitamin B complex, and vitamin D. Forty-seven of the group received rehabilitation sessions in addition to conventional treatment. Rehabilitation techniques included hydrotherapy, massage, heat treatments, manual therapy, and assistive devices such as carts. The study found that a higher proportion of dogs received a good or excellent grade of improvement when rehabilitation was included

TABLE 1 | Modified Frankel Score.

MFS grade	Physical exam findings
Grade 0	Paraplegia with no deep nociception
Grade 1	Paraplegia with no superficial nociception
Grade 2	Paraplegia with nociception
Grade 3b	Non-weight bearing non-ambulatory paraparesis
Grade 3a	Weight bearing non-ambulatory paraparesis
Grade 4	Paraparesis and ataxia
Grade 5	Spinal hyperesthesia only

Source: Levine et al. (19).

in the treatment plan with greater differences noted in more severe injuries. Overall, 89.36% of dogs in the rehabilitation group had a good or excellent improvement compared to 77.14% of dogs in the conventional treatment group. Among dogs with paralysis, the rates drop to 88.46 and 72.22%, respectively (18).

The purpose of this retrospective study is to assess the outcome for dachshunds exhibiting presumed thoracolumbar IVDH who undergo nonsurgical rehabilitation. For patients not pursuing surgery, advanced imaging is often not undertaken due to either expense or feasibility. For many of these cases, a diagnosis of T3-L3 myelopathy with presumed Hansen Type I IVDH is made *via* signalment, physical exam findings, and neuroanatomic localization alone.

The primary objective of this study is to assess the likelihood of a positive case outcome in dachshunds with presumed thoracolumbar Hansen Type I IVDH treated with nonsurgical rehabilitation given the severity of neurologic signs at presentation. The primary hypothesis is that in dachshunds treated with nonsurgical rehabilitation, a positive functional outcome at 12 weeks is associated with the severity of neurologic signs at presentation as defined by a Modified Frankel Score (MFS) (19). A secondary objective is to describe the incidence and timing of recurrent T3-L3 myelopathy in dogs that are successfully treated with rehabilitation by 12 weeks postinjury.

MATERIALS AND METHODS

This study was conducted as a retrospective analysis of medical records from the Fort Collins Veterinary Emergency and Rehabilitation Hospital from January 2010 through October 2020. The electronic medical record database was searched for all records of dachshunds and dachshund mixed breed dogs that presented to the hospital during the study period. These were then screened to include only dachshunds who had at least one visit to the rehabilitation department. The remaining medical records were then read and assessed by a rehabilitation-certified veterinarian (JS) to verify if cases met the selection criteria. Records were selected for inclusion in the study if the animal presented to the rehabilitation service and was diagnosed with T3-L3 myelopathy prior to the visit or at the initial evaluation. Clinical signs must have been present for 30 days or less before presentation to the rehabilitation

Abbreviations: IVDH, intervertebral disk herniation; HBOT, hyperbaric oxygen therapy; MFS, Modified Frankel Score; NMES, neuromuscular electrical stimulation; PEMF, pulsed electromagnetic field therapy; TENS, transcutaneous electrical nerve stimulation.

TABLE 2 | Number of patients receiving various rehabilitation treatment modalities.

	Acupuncture	Electroacupuncture	Therapeutic exercise	Gait training	Laser	Manual	HBOT	PEMF	NMES/TENS
Yes	40	21	40	38	39	38	10	9	8
No	0	19	0	2	1	2	30	31	32

service. Dogs who received care in the acute phase of injury by other departments or facilities were not excluded from the analysis. The patient must have completed a full initial evaluation with the rehabilitation service to be included. Exclusion criteria included: chronic cases with signs lasting for more than 30 days prior to presentation, history of hemilaminectomy or other spinal surgery, multifocal neurologic disease (e.g., history of concurrent cervical or lumbosacral injury), or incomplete medical records.

Medical records were evaluated for sex, age, and MFS at presentation as defined in **Table 1**, as well as outcome 12 weeks after presentation. A positive outcome was defined as an animal who had regained the ability to be a functional pet: urinary and fecal continence, the ability to ambulate without assistance, absent to minimal neurologic deficits (mild proprioceptive deficits in hindlimbs acceptable), and satisfactory pain management such that owner reports no limitations on the dog's quality of life (as determined through visit history forms).

All dogs underwent rehabilitation under the guidance of a veterinarian certified in canine rehabilitation or board-certified in canine rehabilitation and sports medicine. Individual protocols varied based on patient needs and owner availability. In general, rehabilitation protocols included a combination of the following: therapeutic exercise, gait training (underwater treadmill or supported land ambulation), photobiomodulation, manual therapy, acupuncture/electroacupuncture, TENS, NMES, and PEMF. Patients were prescribed medications as needed to manage pain, inflammation, and urinary bladder dysfunction. Most patients were prescribed a home exercise plan to be completed by the owners. Some patients received over-the-counter supplements including fish oil and curcumin. Additionally, some patients received HBOT.

In order to assess the likelihood of recurrence, the length of follow-up after 12 weeks was recorded for all cases with successful treatment outcomes. A recurrence was defined as a loss of functional pet status as defined above, e.g., loss of unsupported ambulation, spinal hyperesthesia, loss of continence, etc.

Statistical analysis was performed with computer software.[1] The population rate of positive outcome was estimated with an exact binomial confidence interval. Wilcoxon rank-sum test was used to compare MFS on a 0–5 scale according to a positive outcome at 12 weeks as defined above. Life table methods were used to estimate 1- and 2-year recurrence rates among dogs with positive outcomes at 12 weeks; dogs that died or were lost to follow-up without experiencing recurrence and dogs that were alive without recurrence at the time of data collection were censored at their last known live dates. Tests were 2-sided and $p < 0.05$ was statistically significant.

RESULTS

A total of 49 cases met the criteria for inclusion in the study. Of these, 23 were neutered males, 23 were spayed females, 2 were intact males, and 1 was an intact female. The median age at presentation was 7 years (Range: 3–15 years). The median duration of signs prior to presentation to the rehabilitation service was 3 days (Range: 1–30 days). Of the 49 cases, 9 were lost to follow-up during the study period.

For the 40 dogs with complete records, at the time of initial evaluation by the rehabilitation service, 4 dogs were lacking deep nociception (MFS = 0), 4 dogs had deep nociception but were lacking superficial nociception (MFS = 1), 5 dogs exhibited paraplegia with nociception (MFS = 2), 7 dogs exhibited nonweight bearing nonambulatory paraparesis (MFS = 3b), 8 dogs exhibited weight-bearing nonambulatory paraparesis (MFS = 3a), 10 dogs exhibited paraparesis and ataxia (MFS=4), and 2 dogs exhibited spinal hyperesthesia only (MFS = 5).

The median number of rehabilitation visits (including inpatient treatment days) was 9 visits over the 12-week study period (range 1–31). Eleven patients received inpatient rehabilitation associated with their initial presentation. Most patients started with a visit frequency of 1–2 visits per week (range: every other week to 3 visits per week). Visit frequency decreased over the 12 weeks of treatment. Visits ranged from 30 to 60 min.

Ten of the dogs had spinal radiographs prior to the rehabilitation evaluation. One dog had spinal magnetic resonance imaging prior to evaluation which confirmed Hansen Type I disc extrusion at T12-13 and multiple mild disc protrusions between T13 and S1.

Treatment modalities received are summarized in **Table 2** and were uniform across MFS groups. Acupuncture and therapeutic exercise were performed on all patients. Electroacupuncture was performed whenever possible due to patient tolerance (21 of 40 patients). Gait training (underwater treadmill or supported land ambulation) was performed with all but 2 patients. The 2 who did not receive gait training were euthanized before this treatment could be implemented. Photobiomodulation therapy was performed on all but 1 patient who had a previously excised soft tissue sarcoma. All but 2 patients received manual therapy as part of their treatment protocol. No explanation was

[1]StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC.

TABLE 3 | Delay between the development of signs and initiation of rehabilitation.

Delay (days)	Number of dogs
0	16
1–2	6
3–5	10
6–14	4
15–30	4

presented in the records for the lack of manual therapy in these cases.

Less commonly, HBOT, PEMF, and TENS or NMES were included in care (10, 9, and 8 patients, respectively). Hyperbaric oxygen did not become available as a treatment modality in the hospital until late in 2015, midway through the study period. After that time HBOT was offered as part of therapy but occasionally declined by owners due to additional expense. PEMF was not available as a treatment modality in the hospital until 2017. Once available, PEMF was included in visits at no additional cost and used for the majority of patients. NMES was used in cases with poor muscle engagement in conjunction with therapeutic exercise. TENS was used infrequently for patients that did not tolerate electroacupuncture.

Of the 40 dogs in the study, 34 had a positive outcome at 12 weeks after the presentation [85.0%, 95% confidence interval (CI) 70.2–94.2]. Of the 6 dogs without a positive outcome at 12 weeks, 4 had been euthanized and 2 had improved but not yet achieved the functional pet criteria. These 2 continued in rehabilitation past 12 weeks.

The time between the initial development of signs and initiation of rehabilitation is summarized in **Table 3**. Three of the 4 dogs that were euthanized during the study had started treatment the same day as signs developed, the fourth dog had a 10-day delay in rehabilitation. Of the 2 remaining dogs without a positive outcome at 12 weeks, 1 had no delay of rehabilitation and the other had a 30-day delay. Treatment was initiated within the first 48 h of signs for over half of the dogs in the study.

Outcome at 12 weeks by MFS at presentation is presented in **Table 4**. Modified Frankel Score at presentation was significantly ($p < 0.001$) higher in the 34 dogs with a positive outcome at 12 weeks (median score 3.5, range 1–5, stands for interquartile range (IQR) 3–4) compared to the 6 dogs that did not have a positive outcome at 12 weeks (median score 0, range 0–2, IQR 0–1). All 27 dogs exhibiting paraparesis, ataxia, or back pain at presentation (MFS 3b or higher), achieved a positive outcome by 12 weeks. Of the 9 dogs exhibiting paraplegia with intact deep nociception at presentation (MFS 1 and 2), 7 dogs (77.8%) had achieved a positive outcome by 12 weeks. Of the dogs in this category with a negative outcome, the dachshund with an MFS of 2 at presentation did not regain independent ambulation. This animal used a cart at home to ambulate and eventually died of other causes. The dachshund with an MFS of 1 at presentation did eventually regain independent ambulation but a positive outcome was not achieved until 26 weeks after presentation. Of the 4 dogs exhibiting paraplegia with persistent loss of deep nociception (MFS 0), none had a positive outcome by 12 weeks, and all 4 were euthanized prior to 12 weeks due to poor condition (1 dog) or a declining condition consistent with progressive spinal cord myelomalacia (3 dogs) (20).

As shown in **Figure 1**, of the 40 dogs with complete records, 36 (90.0%) improved by at least one MFS grade over the course of treatment. Fifteen dogs (37.5%) improved by 3 or more MFS grades. The 4 dogs that did not improve were euthanized during the treatment period.

A review of the records found that 6 of the dachshunds in this study had a history of absent or questionable deep nociception prior to presentation to the rehabilitation service, but deep nociception was noted on initial evaluation. Of these 6, 1 was lost to follow-up, 2 had delayed recovery or incomplete recovery (the negative outcomes from MFS 1 and 2 discussed above), and 3 had a positive outcome by 12 weeks after presentation.

Of the 34 dachshunds with a successful outcome, follow-up records were available beyond the 12-week study period for 27 individuals. The median length of follow-up was 700 days (range: 14–2839 days). The overall rate of recurrence was 14.8% (4/27). Estimated 1- and 2-year recurrence rates were 5.0% (95% CI 0.07–30.5) and 11.3% (95% CI 2.9–38.6), respectively. Four dachshunds had a relapse of signs severe enough to lose functional pet status. One was briefly hospitalized for spinal hyperesthesia and completed another month of rehabilitation to get back to their baseline level of pain control. Two developed weight-bearing paraparesis (MFS 3a) which was resolved with further rehabilitation. One developed paraplegia with intact nociception (MFS 2) and was referred to a neurologist where Hansen Type I intervertebral disc extrusion was confirmed at L1-2 and decompressed *via* hemilaminectomy. The times to recurrence in these 4 dogs were 322, 587, 909, and 1,263 days post-therapy. Overall median time to recurrence could not be estimated in the population due to the low number of events.

DISCUSSION

In this cohort of dachshunds with presumed Hansen Type I thoracolumbar IVDH, dogs with intact deep nociception, both with and without motor function and superficial nociception, at the time of treatment with nonsurgical rehabilitation had a high rate of return to functional pet status by 12 weeks postinjury. Due to the small number of dogs in each MFS category, further study in a larger cohort is needed to determine whether there are clinically relevant differences in prognosis for return to function between individual MFS categories. None of the 4 dogs lacking deep nociception at the time of treatment achieved functional status in this study. These results align with the surgical literature which finds that dogs with no deep nociception prior to hemilaminectomy are less likely to achieve independent ambulation after surgery (6) and that more severe injuries are associated with a longer time to ambulation postoperatively (7). Additionally, it should be noted that 3 of the patients with an MFS score of 0 at presentation showed signs of progressive neurologic deficits

TABLE 4 | Outcome at 12 weeks by Modified Frankel Score (MFS) score at presentation.

	MFS score at presentation							
Outcome at 12 weeks	**0**	**1**	**2**	**3b**	**3a**	**4**	**5**	**Total**
Positive outcome	0	3	4	7	8	10	2	34
Negative outcome	4	1	1	0	0	0	0	6
Lost to follow-up	0	1	2	1	3	2	0	9
								49

and were presumed to be caused by progressive spinal cord myelomalacia (20).

The results of this study correspond with 3 recent retrospective studies that have evaluated the prognosis for dogs in rehabilitation after T3-L3 hemilaminectomy.

Hady and Schwarz looked at dogs receiving rehabilitation postoperatively. Of the 113 dogs, 23 improved one full MFS. The other 89 did not see a full MFS point improvement. More time in formal rehabilitation and additional sessions on the underwater treadmill significantly increased the chances of a full MFS score improvement (13).

Hogdson et al. evaluated 248 dogs who had undergone hemilaminectomy. They found that more dogs returned to full neurologic function when in-house rehabilitation (passive range of motion, therapeutic exercise, and land or underwater treadmill) was included in postoperative management compared to the control group (33 vs. 9%, respectively). Rehabilitation did not seem to accelerate recovery but was associated with a more complete recovery. Additionally, there was also a lower rate of complications in dogs receiving postoperative rehabilitation (14).

Finally, Jeong et al. evaluated the likelihood of a successful neurologic outcome after surgical decompression of thoracolumbar IVDH between a group receiving postoperative rehabilitation and a control that did not receive postoperative rehabilitation. The group receiving rehabilitation was significantly more likely to have a successful outcome and regained unassisted walking and standing more quickly than the control group. The likelihood of a successful outcome was also associated with the severity of neurologic signs prior to surgery (15). These studies taken together indicate that there is merit for the use of rehabilitation techniques in improving the outcome of spinal cord injury secondary to IVDH.

Research in rodent models has shown the necessity of movement and exercise for functional recovery following spinal cord injury (21). Rats whose hindlimbs were immobilized immediately after spinal cord injury exhibited worsening hindlimb motor function. Even when the animals were allowed to move freely at 8 weeks postinjury, the previously immobilized group never regained the level of motor recovery attained by previously unrestrained controls (22). The above canine studies show the benefit of locomotor gait training in the management of presumed Type I Hansen's IVDH in dogs.

A small, prospective, randomized clinical trial of dogs receiving rehabilitation, rehabilitation and photobiomodulation, or sham treatment after hemilaminectomy found no significant difference between treatment groups in return to function 10 days after surgery. The authors speculated that a longer recovery period may be necessary to note the benefits of postoperative rehabilitation and that rehabilitation may be associated with a higher level of recovery (16). A recent randomized, blinded, prospective clinical trial comparing intensive vs. basic postoperative rehabilitation protocols for 14 days after hemilaminectomy for T3-L3 IVDH found no significant difference between the 30 dogs evaluated in both metrics for ambulation and quadrupedal coordination. The authors postulated that the lack of significant difference may reflect the speed of spontaneous recovery in this group of animals, limiting the benefit of the interventions. Postoperative rehabilitation was deemed safe and given the lack of adverse consequences in the intensive treatment group, a more rigorous rehabilitation regimen may have revealed greater differences between the groups. The authors also speculate that rehabilitation may be more beneficial when targeted toward dogs with more severe signs or with a slower recovery postoperatively (17).

Our results are similar to those of Jadeson published in 1961. In his study, 89.36% of dogs in the rehabilitation group had a good or excellent improvement compared to 85.0% in the current study. For paraplegic dogs, the rates drop to 88.46% for the Jadeson study compared to 77.8% in the current study (18).

In clinical cases where the standard of care, including advanced imaging and surgery, is declined, the veterinarian can advise clients that as long as some nociceptive perception is present 24–48 h after the presentation, a good to excellent prognosis is possible with nonsurgical rehabilitation. Rehabilitation still requires a financial and time commitment from the pet owner but can be a viable alternative to surgical treatment in cases with intact pain sensation.

The 24–48 h window allows time for assessment of true nociceptive abilities. In this study, we found that prognosis worsened if deep nociception was not present at the time of treatment initiation. All 4 dogs with absent deep nociception at the initial rehabilitation evaluation were euthanized during the study period. As noted above, 6 dogs in this study had a record of absent nociception at the time of initial presentation to a veterinarian, although nociception was detected at initial presentation to the rehabilitation service, and 3 of these dogs went on to have a positive outcome at 12 weeks.

This discrepancy may speak to the difficulty of assessing deep nociception during the emergent presentation to a veterinarian, either due to patient temperament in the clinic, severe pain immediately post-IVDH, acute but transient spinal cord swelling and bleeding, or the crudeness of a firm toe pinch to rule in or rule out superficial and deep nociception. Some authors have questioned the reliability of toe pinching as a method for detecting deep nociception in dogs (23). Alternatively, some animals may have experienced a transient loss of deep nociception that had been resolved by the initial rehabilitation

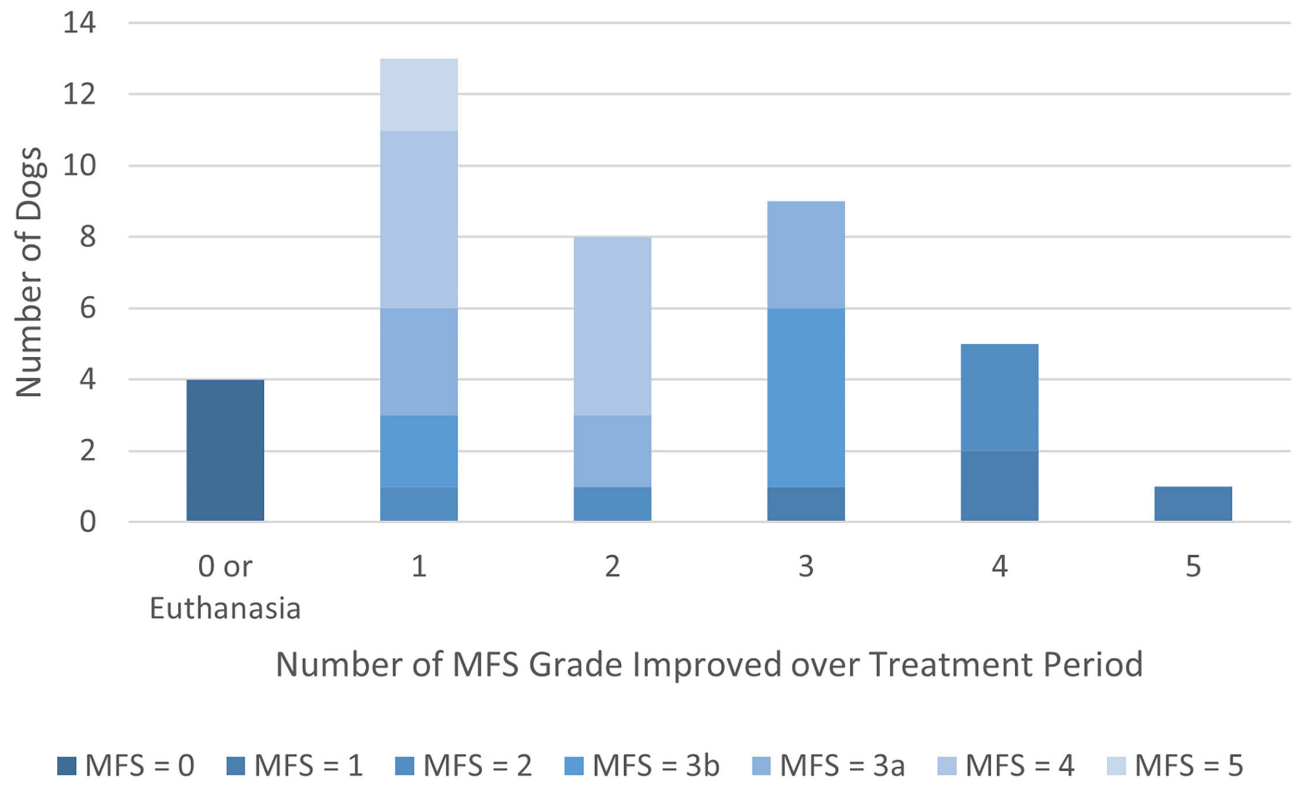

FIGURE 1 | Modified Frankel Score (MFS) grade improvement over treatment period by MFS score at presentation. Shading designates the MFS score at presentation.

evaluation. In the acute phase of spinal cord injury (<24 h), a complete loss of motor and sensory function may be present below the level of an incomplete spinal cord injury due to spinal shock. This would include the loss of deep tendon reflexes and sphincter reflexes. Spinal shock may mask the true degree of injury in the acute period (24). Additionally, rehabilitation veterinarians often employ methods of evoking motor and nociceptive responses in affected limbs using acupuncture or electrical stimulation, which may not be available to clinicians at the initial presentation.

Even cases with a persistent absence of deep nociception may have some chance of recovery with rehabilitation. Joaquim et al. looked at the prognosis for 40 dogs exhibiting signs of severe T3-L3 myelopathy for over 48 h. These dogs received one of 3 treatments: hemilaminectomy alone (10 dogs), hemilaminectomy and electroacupuncture (11 dogs), or electroacupuncture alone (19 dogs). While there was not a significant difference in the proportion of dogs lacking deep nociception in each group prior to treatment, after treatment there were significantly fewer dogs lacking deep nociception in the electroacupuncture-only group. The authors hypothesized that electroacupuncture may help to control the secondary injury cascade through modulation of the immunologic and inflammatory response of the spinal cord (25). Hayashi et al. treated 50 dogs with signs of thoracolumbar IVDH and randomly allocated the dogs to either conservative management (oral steroids, pain medications, activity restriction, bladder management) or electroacupuncture in addition to conservative management. They found that the time to recovery of ambulation was significantly shorter for the group receiving electroacupuncture and that the success rate of achieving unassisted ambulation was higher in dogs receiving electroacupuncture compared to those receiving only conservative management (88.5 and 58.3%, respectively). Three of the 6 dogs in the electroacupuncture group who lacked deep nociception at the start of treatment recovered nociception compared to 1 of 8 dogs in the conservative management-only group (26). This level of recovery in dogs lacking deep nociception is similar to that seen in dogs undergoing surgical intervention in other studies (52.1%) (6). Research on the effects of electroacupuncture after spinal cord injury in rats has found upregulation of the Wnt/β-catenin signaling pathway. This pathway has been shown to be critical in the growth, differentiation, and survival of neurons (27).

If canine patients exhibit a persistent absence of deep nociception (>48 h), and particularly if they show a progression of neurologic signs over 24–48 h, in the face of appropriate pain management and rehabilitation, the prognosis for return to full function is grave.

Of the 34 dachshunds with successful treatment outcomes, we had sufficient records for 27 to assess the likelihood of recurrence. A total of 4 animals (14.8%) exhibited a recurrence of signs severe enough to lose functional pet status, with episodes of worsened neurologic status (MFS 2-3a) or pain episodes requiring hospitalization. Levine et al. reported recurrence of clinical signs in 30.9% of dogs undergoing conservative management without rehabilitation (4), although the smaller sample size in the current study prevents direct comparison to Levine's.

This study is limited by its retrospective nature. An MFS score at presentation must be assigned based on the physical exam findings in the record leaving open the possibility of miscategorization. The authors chose to use the less specific MFS system over the newer and more precise Texas Spinal Cord Injury Score (28), as Van Wie et al. found that the use of the MFS system over the Texas Spinal Cord Injury Score for retrospective studies limits the likelihood of miscategorization (29). There may be some selection bias toward less severe cases in this study if referring veterinarians were more likely to recommend rehabilitation in mild cases. Additionally, there may be a selection bias for owners with a higher commitment to the rehabilitation process. Given the retrospective nature of this study over more than 10 years with 8 different veterinarians, and differences in owner availability, the animals involved did not receive a uniform rehabilitation protocol, although this lack of uniformity would weaken rather than strengthen the significance of our results.

A major limitation of this study is that diagnosis is not confirmed for the majority of patients. Although Hansen's Type I IVDH is a likely cause of T3-L3 myelopathy in dachshunds (1), other etiologies of the disease may be present including neoplasia, vascular events, or infectious and inflammatory disease. Additionally, without imaging it is not possible to determine the severity of disc extrusion or if multiple sites are involved as is often the case for dachshunds with IVDH. This limitation is shared, however, by the veterinarian evaluating these cases at initial presentation when owners decline advanced diagnostics. The authors hope to give a true assessment of the prognosis of nonsurgical rehabilitation in dachshunds, regardless of underlying etiology. We hope that the results of this study will help guide the recommendations of veterinarians faced with seeing these cases in the acute phase when owners are unwilling or unable to pursue advanced imaging and surgery.

Future directions include evaluation of specific rehabilitation treatment protocols with the goal of developing the most cost-effective rehabilitation plan for nonsurgical management of presumed thoracolumbar IVDH in dachshunds. Additionally, long-term monitoring to further illustrate the likelihood of recurrent neurologic deficits or hyperesthesia in animals undergoing nonsurgical rehabilitation compared with animals receiving surgical treatment should be another area of focus. Dachshunds with presumed Hansen Type I IVDH had a good to excellent prognosis for return to status as a functional pet when they presented to a rehabilitation service with sensation or motor function intact. Those patients lacking deep nociception for more than 1–3 days after injury, and especially those with the progression of abnormal neurologic signs, exhibited a grave prognosis. With these results in mind, clinicians should strongly consider rehabilitation as a viable treatment alternative when advanced imaging and surgery are not possible. Additionally, including rehabilitation as a component of conservative management may help to decrease the risk of recurrence of neurologic signs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because the study was a retrospective review of medical records. All animals received appropriate care as determined by the treating veterinarian in consultation with the owner of the animal. Written informed consent for participation was not obtained from owners due to the retrospective nature of the study design. Owners consented to treatment plan presented by treating veterinarian.

AUTHOR CONTRIBUTIONS

JS conducting the retrospective analysis and authoring the manuscript. JR and BW provided guidance in the planning of the study and the authoring of the manuscript. MG conducted the statistical analysis. All authors contributed to the article and approved the submitted version.

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Development and testing of a stifle function score in dogs

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Objective: The purpose of this study was to develop and test a quantitative stifle function score (SFS) in dogs with unilateral cranial cruciate ligament disease by combining clinical measures and functional tests. The objective of this study was to compare the proposed SFS to a symmetry index (SI) calculated from objective ground reaction forces (GRFs). We hypothesized that the SFS would have a strong correlation with SI.

Methods: Dogs with surgically and nonsurgically treated unilateral cranial cruciate ligament rupture and dogs with no known musculoskeletal problems were included in the study. Each dog was scored using the SFS and trotted across a force platform to obtain GRFs and calculate the SI, based on vertical GRFs. Fourteen items were included in the SFS: limb use at a walk, limb use at a trot, lameness at a walk, lameness at a trot, stair climbing, sit-to-stand, dancing, pain response, stifle effusion, thigh circumference/muscle atrophy, stifle extension, stifle flexion, and cranial drawer/tibial thrust, with each item scored based on previously determined criteria. A perfect SFS would receive a score of 100.

Results: Twenty-seven dogs were included in the study: twenty-one with unilateral cranial cruciate ligament disease and six control dogs. The mean SFS was 71.5 out of 100. To further characterize the association between SFS and SI the degree of gait asymmetry using SI was classified as $<5\%$, 5.1–10%, 10.1–20%, 20.1–25%, and $>25\%$ difference between the pelvic limbs for all dogs. The mean SFS for each of the five categories were 97.8, 85.2, 65.4, 63, and 56.4, respectively. Correlation of SI and SFS was −0.863 ($p < 0.0001$). All of the individuals evaluated tests in the score were significantly correlated with SI except for pain response and stifle flexion. The SFS is in strong agreement with the SI, as confirmed by Bland–Altman analysis.

Conclusion: The SFS had a significant correlation and agreement with the SI calculated from GRFs. This SFS may be a useful, simple, and inexpensive tool to use in a clinical environment to monitor progression during the rehabilitation and recovery process following unilateral cranial cruciate ligament rupture.

KEYWORDS
stifle, function, score, dogs, rehabilitation

Introduction

Cranial cruciate ligament rupture (CCLR) is commonly encountered in veterinary medicine. Rehabilitation is thought to be beneficial to dogs with CCLR (1–3). The therapy plan for each dog is determined by an initial evaluation of the dog's function and is altered as they are re-evaluated during their recovery to allow changes in their individual rehabilitation program. The main goals of physical rehabilitation are to return the dog to as normal function as possible and to be able to perform daily-life activities. Currently, monitoring a dog's progress during recovery is based primarily on subjective measures and alterations in rehabilitation are based on the dog's progress or by protocols with expected timeframes during recovery (4). In human medicine, there are several validated objective scoring systems to not only evaluate the knee after injury but also evaluate patient progression following reconstruction of the anterior cruciate ligament (5–7). Some of the items evaluated in these scoring systems include subjective evaluation of pain, swelling, giving way, walking, running, and ascending or descending stairs. Quantitative measures such as goniometry (8), thigh circumference (9, 10), static weight bearing (11), and force plate analysis (12) have previously been used to evaluate a patient's progress in veterinary medicine, but some of these tools are cost-prohibitive or not generally available in private practice. Force plate analysis is an objective measure of assessing lameness in dogs and is commonly used as an outcome measure after cruciate injury (13). However, this only provides objective information regarding weight-bearing at a walk or trot and not overall function. A validated stifle scoring system would be beneficial to evaluate patient progress for canine patients during recovery from CCLR. Two such systems have been proposed and are currently being evaluated (14–17). While both of these systems have been validated to differentiate dogs with and without cruciate ligament rupture, there has been a little comparison between these subjective scoring systems and objective measures, such as GRFs. The proposed scoring system in our study used items similar to validated scoring systems to evaluate knees in people, a variety of subjective and objective items that can be easily assessed in dogs, including some tasks that appear valuable based on other stifle scores in dogs, and was compared with GRFs.

The purpose of this study was to develop and test a quantitative stifle function score (SFS) in dogs with unilateral cranial cruciate ligament disease at different phases of disease by combining clinical measures and functional tests. The main objective of this study was to compare the SFS to a symmetry index (SI) calculated from measured GRFs from force plate analysis. We hypothesized that the SFS would have a strong correlation with the SI. Our overall goal is to provide a more comprehensive quantitative instrument using several items generally believed to be valuable in assessing the progress and outcomes of rehabilitation in dogs and to demonstrate that this SFS may be used to more closely assess the degree of weight-bearing as determined by GRFs.

Materials and methods

Dogs

Client-owned dogs were recruited and enrolled in the study with written owner consent. Inclusion criteria for the study were dogs weighing between 10 and 50 kg, ages 1–12, free of any major systemic illness as determined by physical examination, and appropriate blood tests and urinalysis if indicated. Two study populations were used: dogs with known unilateral cranial cruciate ligament disease were included regardless of when the injury occurred or whether or not surgery had been performed on the injured stifle ($n = 21$) and dogs with no evidence of any orthopedic disease served as controls ($n = 6$). Exclusion criteria included a body condition score >7/9, lameness in forelimbs or pelvic limbs unrelated to cranial cruciate ligament disease, bilateral cranial cruciate ligament disease, or neurologic abnormalities. This study was approved by the University of Tennessee Institutional Animal Care and Use Committee and was performed in accordance with AAALAC and USDA guidelines (No. 2765-0520).

Kinetic analyses

A force platform (AMTI OR6-6, Watertown, MA, USA) was used to obtain GRFs which were then expressed as a percent of body weight. Four valid trials for each side of the dog were obtained at a trot. For a trial to be considered valid, dogs must have had no sudden deviation of gait, sudden head movements, turning of the head during gait, or any other motion that might affect the collection of kinetic data. Velocity and acceleration of the dog and handler were maintained between 1.7 and 2.1 m/s and ± 0.40 m/s^2, respectively, using five photocells and a start-interrupt timer system. Mean peak vertical force values were used to identify weight-bearing asymmetry for each dog. SI was calculated using the equation: $SI = 100 \times abs\frac{(highest\ PVF - lowest\ PVF)}{(highest\ PVF + lowest\ PVF)}$ where a SI of 0% would represent perfect paired limb symmetry (18, 19). The degree of gait asymmetry using SI was further classified as <5%, 5.1–10%, 10.1–20%, 20.1–25%, and >25% difference between pelvic limbs.

Stifle function score

Each dog was scored using the SFS (Supplementary Appendix 1) by the same blinded evaluator

(DM). Fourteen individual tests were included in the score: limb use at a walk, limb use at a trot, lameness at a walk, lameness at a trot, stair climbing, sit-to-stand, dancing, pain response, stifle effusion, thigh circumference/muscle atrophy, stifle extension, stifle flexion, and cranial drawer or tibial thrust. The score ranged from 0 to 100, with a total score of 100 being perfect. The scoring details of each individual test are described in detail in Functional Tests and Clinical Measures. The entire SFS protocol can be viewed in Supplementary Appendix 1.

Functional tests

Limb use at a walk and trot were scored separately from 0 to 10: 10 = No lameness and weight-bearing on all strides, 6 = lame but weight-bearing on >95% of strides, 4 = lame but weight-bearing on >50 and <95% of strides, 2 = lame but weight-bearing on <50 and >5% of strides, and 0 = continuous non-weight-bearing lameness or weight-bearing on <5% of strides. Lameness at a walk and trot were scored separately from 0 to 10: 10 = normal locomotion, 8 = walks/trots with a slight (barely perceptible) lameness, but strides appear to have normal length, 6 = walks/trots with a mild lameness, but strides appear to have normal length, 4 = walks/trots with a moderate (obvious) lameness or a shortened stride length on the affected side when trotting, but is bearing weight on that limb, 2 = is intermittently non-weight-bearing on that limb when walking/trotting, and 0 = is completely non-weight-bearing on that limb when walking/trotting. The stance was scored from 0 to 10: 10 = stands with equal weight on both pelvic limbs, 6 = bears less weight on the affected pelvic limb or limb trembles when standing, 4 = puts limb down for balance but bears <10% of normal weight, and 0 = does not bear weight on an affected limb while standing. Stair climbing was scored from 0 to 5; 5 = no difficulty, 3 = slight difficulty climbing steps, 1 = skips steps or bunny hops, and 0 = cannot climb stairs. Sit-to-stand was scored from 0 to 5: 5 = easily goes from a sitting to a standing or a standing to sitting position/sits and rises squarely and symmetrically, 3 = sits or stands with some difficulty (slight hesitation or delay and mild asymmetry sitting or standing), 1 = sits or stands with difficulty (hesitation or delay and obvious asymmetry sitting or standing), and 0 = cannot sit or stand without assistance. Dancing was performed by lifting the dog's forelimbs off the ground, supporting them, and then moving them forward and backward. It was scored from 0 to 5: 5 = moves freely forward and backward, 3 = resists moving forward and backward, and 0 = unable to bear weight on pelvic limbs during forward and backward dancing motion.

Clinical measures

Pain response on palpation of the stifle joint capsule attachment sites were scored from 0 to 5: 5 = no pain response is elicited during palpation of the joint, 3 = mild pain response (i.e., head-turning) is elicited during palpation of the joint, 1 = moderate pain response (i.e., slight vocalization and increased reaction) is elicited during palpation of the joint, and 0 = severe pain response (i.e., immediate reaction, loud vocalization, and attempt to bite) is elicited during palpation of the joint. The amount of pressure placed on the joint capsule insertion sites was ∼3 kg/cm^2. To help assure reasonable clinical application of this amount of force, the evaluator practiced with a pressure threshold device until a consistent amount of pressure was obtained. Stifle effusion was scored from 0 to 5: 5 = no effusion of stifle, 3 = slight loss of patella ligament distinctness, 1 = patella ligament not distinct, and 0 = cannot distinguish patella ligament due to effusion. Thigh circumference/muscle atrophy was measured using a Gulick II tape measure and as previously described (9). It was scored 0–10: 10 = normal muscle mass, 6 = thigh girth is 1–5% smaller than the opposite limb, 4 = thigh girth is 6–10% smaller than the opposite limb, and 0 = thigh girth is >11% smaller than the opposite limb. Stifle extension and flexion were measured using a commercial goniometer and as previously described (8). Stifle extension was scored from 0 to 5: 5 = extension 160° or more, 3 = extension 150°-159°, 1 = extension 140°-149°, and 0 = extension <139°. Stifle flexion was scored from 0 to 5: 5= flexion 45° or less, 3 = flexion 46°-50°, 1 = flexion 51°-60°, and 0 = flexion >60°. Cranial drawer or tibial thrust was evaluated and scored from 0 to 5: 5 = <2 mm, 3 = 2–4 mm, 1 = 5–7 mm, and 0 = >7 mm. The direct cranial drawer was evaluated in dogs with no surgical correction or surgery with an extracapsular technique, while cranial tibial thrust was used to evaluate dogs following tibial plateau leveling osteotomy surgery or tibial tuberosity advancement surgery.

Statistical analysis

The normality of data was assessed with a Shapiro–Wilk test and it was not normally distributed. Spearman's rank correlation, a nonparametric method, was used to measure the correlation coefficient between individual tests within the SFS and SI (IBM SPSS v.27). A Passing–Bablock regression was run to show the agreement between 1-SFS and SI. Bland–Altman analysis was then performed to also evaluate the agreement between 1-SFS and SI using SI as the gold standard (x-axis) and the difference between 1-SFS and SI as the y-axis (Medcalc v.20). $P < 0.05$ was considered significant.

Results

A total of 27 dogs, 18 females and nine males, with a mean weight of 30.94 kg (median 29.5 kg; range 17.9–47 kg) were included in the analysis. The following breeds were represented: mixed breed (n = 14), Labrador Retriever (n = 5), German Shepherd (n = 3), Golden Retriever (n = 2), Standard Poodle

TABLE 1 Spearman correlation between SI and other variables.

	Spearman correlation with SI	*P*-value (2-tailed)
SFS	−0.863**	<0.0001
Limb use at walk (10)	−0.808**	<0.0001
Limb use at trot (10)	−0.804**	<0.0001
Lameness at walk (10)	−0.784**	<0.0001
Lameness at trot (10)	−0.819**	<0.0001
Stance (5)	−0.723**	<0.0001
Stairs (5)	−0.576**	0.002
Sit-to-stand (5)	−0.618**	0.001
Dancing (5)	−0.797**	<0.0001
Pain (5)	−0.353	0.071
Stifle effusion (5)	−0.422*	0.028
Muscle atrophy (10)	−0.568**	0.002
Stifle extension (5)	−0.590**	0.001
Stifle flexion (5)	0.05	0.803
Cranial drawer/tibial thrust (5)	−0.824**	<0.0001

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

($n = 1$), Golden Doodle ($n = 1$), and Doberman ($n = 1$). Twenty-one dogs with unilateral cruciate ligament disease and six control dogs were included. Of the 21 affected dogs, 11 presented with acute unilateral complete cranial cruciate rupture (later confirmed during surgery), six had Tibial Plateau Leveling Osteotomy (TPLO) surgery performed 8 weeks prior, one had TPLO surgery 3 weeks prior, one had TPLO surgery 5 months prior, one had TPLO surgery 2 years prior, and one had suspected unilateral partial cranial cruciate tear. The mean SFS of this group was 71.56 out of 100. The mean SFS for each of the five categories of SI (<5%, 5–10%, 10–20%, 20–25%, and >25% difference) were 97.8, 85.2, 65.4, 63, and 56.4, respectively. Correlation of SI and SFS was −0.86 ($p < 0.0001$, Table 1). All of the individual tests in the SFS score were significantly correlated with SI except for pain response and stifle flexion (Table 1). The intercept of Passing–Bablok regression estimation was 5.225 with the 95% CI ranging from −0.4686 to 11.9159, and the slope estimation is 0.8377 with the 95% CI ranging from 0.6542 to 1.1006. The intercept 95% CI includes 0 and the slope 95% CI includes 1, indicating there is no significant difference between the intercept and 0 (the systematic difference between the two methods), and between the slope and 1 (the proportional differences between the two methods) (Figure 1).

The total SFS was in strong agreement with SI, as confirmed by the Bland-Altman analysis (Figure 2). The 1-SFS vs. SI bias mean was 2.9 with an SD of 14.66. The 95% limit of agreement ranged from −25.802 to 31.67. The Bland–Altman plot showed that the SFS overestimated SI when the SI value range was 0–20 (more symmetric) and underestimated SI when SI > 40 (more asymmetric) (Figure 2).

Discussion

The main purpose of this study was to develop and test a quantitative SFS in dogs with unilateral cranial cruciate ligament disease based on commonly used clinical parameters and functional tests and to compare this SFS with objective force platform analysis. Development of the score consisted of combining both clinical measures and functional tests to better assess a dog's overall stifle function. These items were chosen based on previous studies that evaluated stifle function following cruciate injury and clinical experience in evaluating the function of patients with cranial cruciate ligament disease (20). We accept our hypothesis that the SFS would have a strong correlation with SI based on objective GRFs. Correlation of SI and SFS was −0.86 ($p < 0.0001$).

Measurement of GRFs using a force platform was used to evaluate the SFS and is a potential weakness of this study. GRFs are a highly sensitive method of evaluating lameness, but may not be a true measure of functionality in patients with cruciate ligament disease. Unfortunately in veterinary medicine, there is no current gold standard for evaluation of a dog's overall function in regards to stifle disease. Knee function in people is commonly assessed using subjective criteria, and these scoring systems are in common use, but require the input of the patient in scoring many of the items. We chose to use GRFs to compare our SFS because it is an objective measure of weight-bearing, does not require patient input, and has excellent sensitivity and specificity in detecting lameness. The sensitivity of subjective or visual lameness scores is relatively low unless severe lameness is present (20).

To further assess the SFS, we tested the agreement between SFS and SI using Bland–Altman analysis, using SI as the gold standard test. This analysis showed good overall agreement between SFS and SI. The Bland–Altman analysis also showed that the SFS tended to be higher (overestimated function of the patient) when the SI value range was 0–20 (more symmetric) and tended to be lower (underestimated function of the patient) when SI > 40. This overestimation and underestimation may be due to limitations in the degree of function and distribution of the study population regarding the degree of disability of patients with CCLR. Some of the study dogs presented with acute CCLR that had not yet been surgically corrected or control patients. This resulted in very low SFS and higher SI for dogs with acute CCLR, and very high SFS and lower SI in normal dogs. More patients at various stages of recovery after surgery or further along in recovery with conservative management may have resulted in greater data

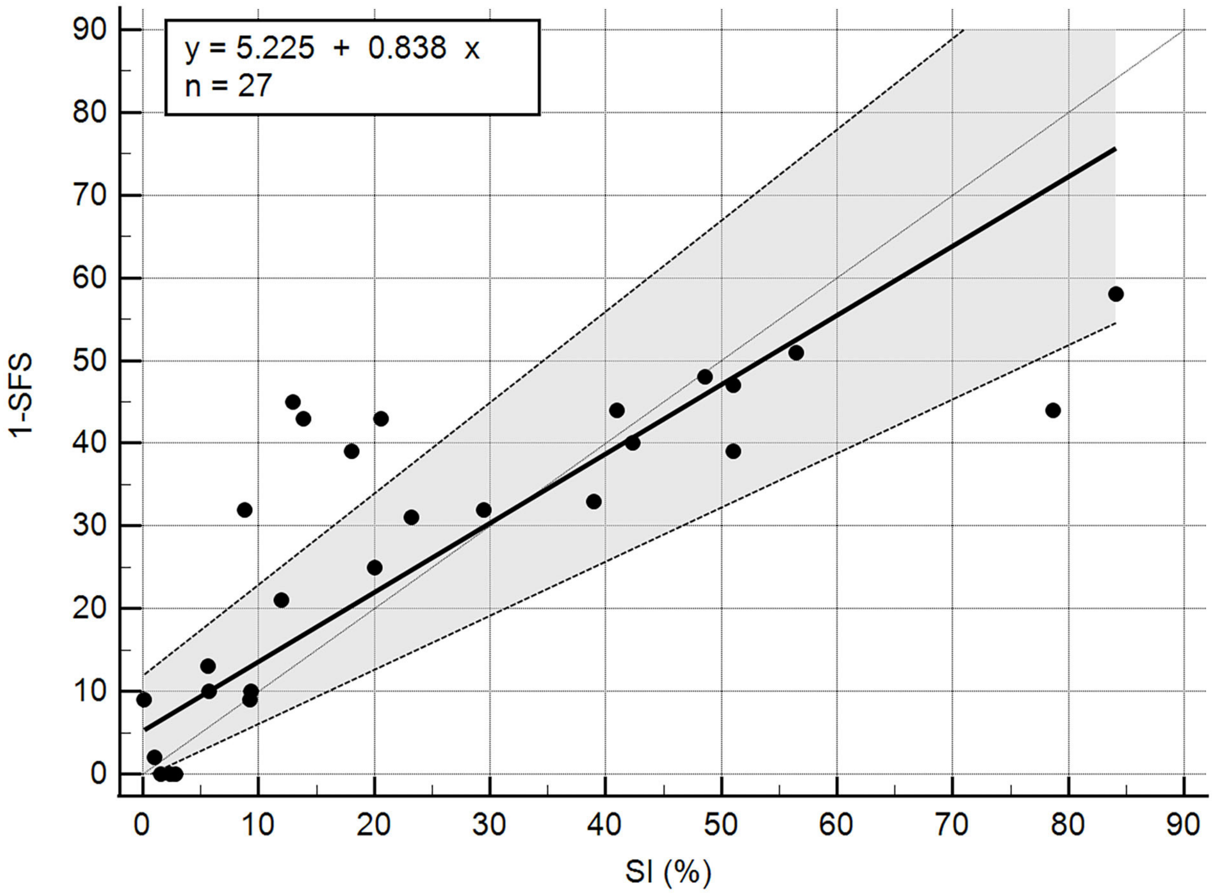

FIGURE 1
Passing Bablok regression of 1-SFS and SI (%).

spread with fewer extremes. Nevertheless, the SFS was able to discern dogs that were doing well in terms of function from those that still had significant mobility issues as a result of their CCLR. Another explanation for overestimating or underestimating the function of patients may be due to the weighing of various test items. For example, patients with poor limb use (percentage of strides that the patient bears some weight on the limb) also received low scores regarding lameness. While the intent of the SFS was to capture those patients with consistent use of the limb, yet still having various degrees of lameness, it also severely penalizes those dogs that have intermittent limb use as also being severely lame. Using GRFs as the comparison to our SFS could also explain the overestimation and underestimation seen in the analysis because the agreement of subjective lameness scores is greatest at either end of the lameness spectrum (i.e., no lameness or severe lameness) (20).

Individualized tests within the SFS were also evaluated to better assess items in the score to determine if each item contributes to the total functional score. Development of the score and deciding which items to include was based on previous studies that ranked evaluation methods for the canine stifle (21). The evaluation methods in that ranking included thigh circumference, sitting position, static weight-bearing, stifle range of motion, stair climbing, and visual evaluation of lameness (21). Based on our clinical experience, these evaluation methods and additional components were added to the SFS. In the proposed SFS, all the individual tests were significantly correlated with SI except for pain response and stifle flexion. The pain response test was based on palpation of the joint around joint capsule insertion sites rather than if the dog was painful throughout the range of motion or during hyperextension of the stifle. It is possible that many dogs were not painful on passive palpation of the stifle joint but might be with stifle manipulation. It is also possible that due to the dogs' temperament, more or fewer signs of pain may be exhibited due to anxiety in the clinic or other factors. Stifle flexion may also not be a very discriminating test in the SFS because many dogs maintained normal stifle flexion regardless of their SI. This is consistent with other studies that have suggested dogs with greater degrees of lameness generally also have decreased extension, but usually have normal stifle

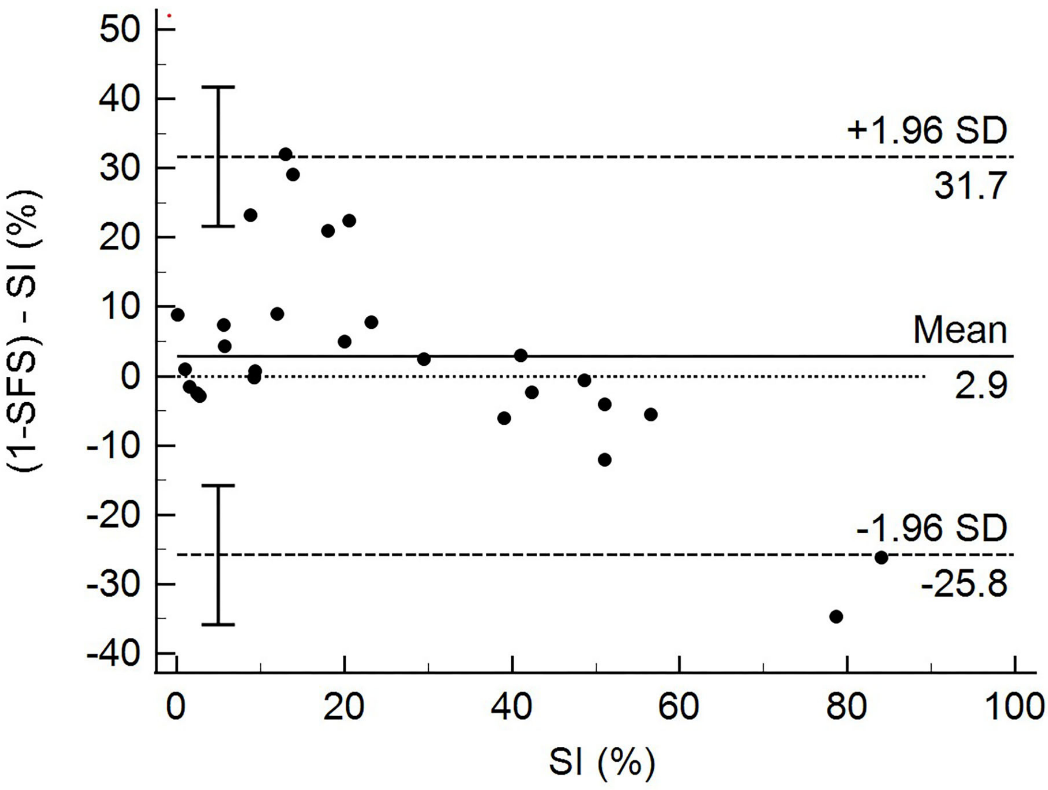

FIGURE 2
Graphic representation of Bland-Altman plot between (1-SFS) - SI (%) and SI %.

flexion (22). It should be noted that while some studies show variable results when measuring thigh circumference, the thigh circumference technique used in this study has demonstrated good repeatability (9).

While the SFS was developed to assess patient function in a clinical environment with the goals of ease of use, obtaining accurate results, and minimal amount and cost of equipment, it does require a goniometer and Gulick II tape measure. This equipment is affordable and easily accessible to veterinarians and physical therapists, and the use of the equipment is feasible in determining the SFS.

We are aware of two other stifle injury scores in veterinary medicine (14, 16, 17). Both testing instruments have been used to compare normal dogs to dogs after surgical correction of CCLR. One of these scores has been used to detect stifle dysfunction and develop a numerical cut-off value between "adequate" and "compromised" stifles (14). Furthermore, this study was not performed with blinding relative to the stifle condition, and this scoring system had the weakest sensitivity and specificity with GRF measures. The other scoring system compared different surgical techniques during the healing process with evaluations 1, 3, and 6 months after surgery (16, 17). Because the scoring system used in this study had owner assessment as a large part of the score and the comparison of dogs 1 month after surgery compared to normal dogs, there is the potential for tremendous bias in scoring these patients. Although we cannot definitively state that this SFS is superior to others, we believe that our SFS is an improvement over these other scores because of comparison to normal dogs, the blinding incorporated in the study design, the evaluation of dogs at random times during recovery, and the comparison to and high correlation with objective weight-bearing using GRFs. Therefore, this SFS may be useful to evaluate a dog's progress throughout injury, recovery, and rehabilitation rather than as a diagnostic tool for cruciate disease or to evaluate different surgical techniques. The use of this score may allow clinical decision-making regarding alterations in activity for a patient. In addition, the proposed SFS uses functional tests and clinical measures and does not include an owner questionnaire as one of the scoring systems does. While the hope is that the SFS may eventually be used to assess dogs with other stifle conditions such as patella luxation, osteochondritis dissecans, and osteoarthritis; we chose the evaluation of unilateral cranial cruciate ligament disease for the initial study to restrict the variable of other stifle conditions. We hope that the SFS can be further tested using other clinical conditions to validate its use for other conditions.

One limitation of this study is the low number of participating dogs as a result of the suspension of elective orthopedic procedures at the hospital during the COVID pandemic. Despite limited patient enrollment, we believe that evaluation of the SFS was sufficiently robust, and confirmed with appropriate statistical tests, to allow recommendations to use the instrument to assess patient disability and perhaps assess patient progress. Another limitation is that dogs were assessed at different stages of recovery from CCLR. This was by design to allow assessment of dogs during different stages of stifle dysfunction. We believe that evaluation of dogs at various stages of cranial cruciate ligament disease, including presurgical and postsurgical cases, strengthens the usefulness of the SFS when comparing the score with objective GRFs, which was the primary objective of this study. Because a heterogenous population was used to look at various stages of stifle injury and recovery, other confounding factors of stifle injury such as meniscal injury or severity of degenerative joint disease were not considered, but it is likely that they contributed to decreased GRFs and SFS values. The purpose of the study was not to evaluate the outcome or chronicity of the disease, but to evaluate if the score was a valid indicator of the degree of lameness and function. Future research may use the SFS to evaluate other factors involved in cruciate ligament disease, including the condition of the meniscus and degree of osteoarthritis, and also recovery from surgery and the evaluation of postoperative rehabilitation programs. Based on our results, the proposed SFS is a relatively sensitive instrument for the clinical evaluation of stifle function and may be able to identify more subtle changes as compared to other scoring systems. Ideally, the SFS would be a useful tool to measure a dog's progress throughout injury and rehabilitation rather than a diagnostic tool to distinguish between normal and abnormal dogs. While some dogs were scored at least two times during the recovery, there were not adequate numbers to make inferences regarding the usefulness of the SFS to monitor progress. But based on the high correlation of the SFS with SI, it is suspected that it would be a useful tool. However, further evaluation of its utility as a clinical tool must undergo additional rigorous testing, including determination of intraobserver and interobserver variability and correlation with GRFs before incorporating this scoring system into global use.

Despite the limitations of the study reported here, a quantitative SFS was developed and effectively tested in dogs with unilateral cranial cruciate ligament disease. Our results support the use of the SFS in a clinical environment to assess disability in dogs following cranial cruciate ligament disease with minimal equipment.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was reviewed and approved by Institutional Animal Care and Use Committee. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.895567/full#supplementary-material

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Prospective evaluation of complications associated with orthosis and prosthesis use in canine patients

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Introduction: The use of orthoses and prostheses is expanding in veterinary medicine. However, research evaluating the efficacy and complications of these devices in veterinary patients is limited. The primary objective of this study was to prospectively determine the complications and outcomes associated with custom orthosis and prosthesis use in the canine patient.

Materials and methods: This was a prospective, clinical trial that followed patients for 12 months following device fitting. Owner-perceived complications, clinical metrology instruments, and objective gait analysis were used as outcome measures at various time points. The patients were grouped into the following four major categories: Patients with a carpal orthosis, patients with a stifle orthosis, patients with a tarsal orthosis, and patients with a prosthetic device.

Results: Forty-three patients were included in the study. Thirty-nine out of 43 patients (91%) experienced at least one complication, with 7/7 (100%) prosthesis patients experiencing at least one complication. At least one skin complication was reported for the following patient groups during the first 3 months of use: 8/14 (58%) stifle orthoses, 9/10 (90%) carpal orthoses, 6/10 (60%) tarsal orthoses, and 4/7 (58%) prostheses. Patient non-acceptance of the device was identified in 2/15 (14%) stifle orthoses, 1/10 (10%) tarsal orthoses, and 4/7 (55%) prostheses. One out of 15 (7%) stifle orthoses, 4/10 (40%) carpal orthoses, 4/10 (40%) tarsal orthoses, and 1/7 (15%) prostheses experienced mechanical device problems necessitating repair. The majority of patients with carpal and stifle orthoses showed improvement on objective gait analysis in percent body weight distribution of the affected limb between baseline and the most recent follow-up without the device donned: 83% ($n = 6$) of patients with carpal orthoses, 100% ($n = 11$) of patients with stifle orthoses. None of the patients with tarsal orthoses showed a similar improvement (0%; $n = 4$).

Discussion and conclusion: Three major complications associated with canine orthosis and prosthesis use were identified in this study as follows: Skin complications (abrasions, loss of hair, and sores), mechanical device problems, and patient non-acceptance of the device. Owners should be notified of these potential complications prior to pursuing orthoses or prostheses as a potential treatment option. Although clinical improvement was noted in the majority of patients with stifle and carpal pathology, given the lack of a control group, it is unknown how much of this improvement can be attributed to the orthoses.

KEYWORDS

orthotic, prosthetic, rehabilitation, orthopedics, dog, cranial cruciate ligament disease

Introduction

The use of orthoses and prostheses in companion animals has become increasingly popular in veterinary medicine (1). Orthoses have a variety of orthopedic applications and can serve to restrict, control or assist with motion, and/or function as a protective device (1). Bertocci et al. found that ∼51% of owners were interested in non-surgical intervention for the treatment of cranial cruciate ligament disease (CCLD) due to misgivings about surgical intervention, while 29% sought an orthosis due to the cost associated with surgical intervention (2). Prostheses enable use of an incomplete limb resulting from either amputation or a congenital defect (1, 3).

Despite this emerging popularity and variety of applications, research evaluating the efficacy and complications of orthoses and prostheses in veterinary patients is limited. There has been multitudinous research in human medicine on the topic, but the significant differences in the anatomy and gait of veterinary patients warrants research specific to companion animals.

The available veterinary research suggests that orthoses may play a role in decreasing lameness and pain associated with several conditions in companion animals (4–8). Tomlinson et al. retrospectively reviewed canine patients with carpal ligament instability and found return to normal function for 79% of patients with significantly improved lameness scores in patients with carpal ligament instability that was refractory to cage rest. Hart et al. found that 88% of dogs wearing stifle orthoses for CCLD had mild to no lameness at the conclusion of the study based on owner assessment (5). However, the previously mentioned studies relied on subjective outcome measures of lameness exclusively, utilizing visual lameness scoring and client surveys to determine degree of lameness and overall outcome. Bertocci et al. showed improved joint stifle mechanics associated with application of an orthosis for CCLD compared to a cranial cruciate ligament deficient stifle in a computer model (6). Case et al. demonstrated improvement in a dog with Type 2c common calcanean tendinopathy treated with both an orthosis and mesenchymal stem cell transplantation (7). This case report did utilize force plate gait analysis as an objective outcome measure. A retrospective study by Carr et al. utilized a pressure sensitive walkway to evaluate a carefully selected group of 10 dogs fitted with a stifle orthosis for CCLD. This study showed an improvement of total pressure index of 5.1% in the affected limb after 90 or more days when compared to baseline (8). Given the concurrent use of other treatments and lack of appropriate control groups, determination of the effectiveness of the orthotic alone is unclear.

In addition to the lack of clear knowledge of the benefits of these devices, one of the major complications associated with the application of veterinary orthotics or prosthetics (VOP) is skin sores. Mechanical forces applied to the skin by an orthosis may result in loss of integrity to the skin (9). At the time of writing, no study has prospectively evaluated complications associated with the application of canine orthoses.

The available socket prosthesis research suggests that owner satisfaction and quality of life with these devices is high, despite considerable complication rates (3, 10, 11). In a study by Wendland et al., 96% of surveyed owners indicated that they would elect to utilize a prosthesis as a treatment option again and 89% of patients were shown to have acceptable to full function based on author-defined clinical outcome scoring criteria (3). In a study by Phillips et al., 8/12 dogs fitted with a socket prosthesis had a good outcome overall and quality of life remained good or excellent in 10/12 dogs (10). In a study by Carr et al., 50% of surveyed owners reported that the patient's mobility had improved with the application of the prosthesis and 37.5% of surveyed owners reported no change in the patient's mobility (11). A retrospective case series on intraosseous transcutaneous amputation prostheses (ITAP) for limb-sparing in malignant neoplasia reported that all dogs had pain-free limb function following application (12).

Several studies have reported on complications associated with socket prosthesis use, including development of sores, prosthesis failure (device breaking), and poor patient compliance in using the prosthesis (3, 10, 11). The primary reported complication with ITAP in canine patient is endoprosthesis fracture which was managed with replacement of the ITAP. There were no reported skin complications reported with ITAP in canine patients (12). However, all these studies were retrospective in nature and no prospective studies regarding use of socket or intraosseous prostheses in canine patients have been published to date. Other concerns with ITAP include the higher cost, need for specialized equipment/implants, possibility of complications with the internal fixation, and the implant-skin interface.

While orthoses have been suggested to provide a valuable, less invasive alternative for certain musculoskeletal conditions, and prostheses have been suggested to be a viable replacement for incomplete limbs, more objective data is needed to aid veterinarians and owners in the decision process when considering these novel treatment options. The primary goal of this study was to prospectively determine the type and incidence of complications associated with application of orthoses and prostheses in canine patients.

Materials and methods

Participation in the study was offered to all canine patients that presented to the Colorado State University Veterinary Teaching Hospital (CSU-VTH) over a 2-year period (2018–2020) for lameness or mobility concerns related to musculoskeletal pathology that was deemed to benefit from a custom VOP. There were no other specific inclusion criteria established, such as requirements regarding patient age or size. Dogs who were diagnosed with concomitant neurologic conditions that affected their gait or dogs that were non-compliant/aggressive (unlikely to tolerate device application or gait analysis) were deemed ineligible for the study. Study visits were planned at device fitting (baseline), 3, 6, and 12 months after fitting. Veterinary examinations were performed at these visits to subjectively assess patient progress, check for development of comorbidities, and determine if adjustments to the devices were warranted. Incentives for participation included waived examination and some diagnostic fees at the study visits, a 50% discount for one device, and an additional $600 reimbursement (approximately the second half of the cost of the device) for the completion of all study visits and surveys to encourage a continued participation.

The study protocol was approved by the CSU-VTH Clinical Review Board (VCS #2018-171). Patient care, including pain management and physical therapy, was dictated by the residents and faculty members of the Orthopedic Medicine and Mobility service at the James L. Voss Veterinary Teaching Hospital and decisions related to their care were made independent of the study.

Surveys

Online survey

An online survey (Table 1) was developed to collect information regarding device complications, owner-reported outcomes and satisfaction, device use, concurrent therapies, and changes to the patient's daily life. Surveys were sent by email monthly for 12 months, with the first survey sent 1 month after orthosis or prosthesis fitting via the Survey Monkey online platform (www.surveymonkey.com). If a patient was fitted for bilateral devices simultaneously, the owner received one survey for both devices. If a patient was fitted for bilateral devices at different time points, the owner received a separate survey for each device.

Only patients with complete surveys from at least the first 3 months were included in data analysis. The survey responses were evaluated by one author (SR) for consistency and accuracy. Whether a patient experienced a complication (for example, a skin complication) was determined based on whether a free-response description of that complication was provided.

Skin complication severity was categorized based on the description provided by the owners. Minor skin complications were defined as owner-described loss of hair, irritation, or small sores. Major skin complications were defined as owner-described bleeding, large sores, or signs of infection. An owner description that was vague or unclear was labeled "unknown." Two of the authors (SR and FD) reviewed the descriptions and agreed on categories for the descriptions provided. Other device complications were noted if they were mentioned in any of the free-response sections of the survey.

Client specific outcome measures

Owners completed the activity component of the CSOM questionnaire using methodologies previously published (13). Owners were asked to pick up to five time and place specific problematic activities and grade them on a scale of 1–5 (1 = no problem, 2 = a little problematic, 3 = quite problematic, 4 = severely problematic, and 5 = impossible). The questionnaire was collected at baseline, 3, 6, and 12 months after fitting and completed in dependent fashion, with the grades established at the previous timepoints available to the owner for comparison. The average of these scores was taken to determine a combined score at each timepoint, with a decrease in score indicating improvement. The owners did not complete the behavior component of the CSOM questionnaire.

Objective gait analysis

The objective gait analysis using a pressure sensitive walkway (Tekscan HRV Walkway 6 VersaTek system, Tekscan Inc., South Boston, MA) analysis system was collected at baseline, 3 months after fitting, 6 months after fitting, and 12 months after fitting. The patients were weighed at each visit prior to collection of OGA data, both without their device and with their device so accurate weights could be used for gait data with and without the device. The patients were evaluated at a walk, pace, or trot, based on patient self-selected gaits at baseline and recommended restrictions for each patient based on diagnosed pathology. For example, all patients with common calcaneal tendinopathy were evaluated at a walk. The OGA data was collected using a previously described protocol (14, 15). Three

TABLE 1 Online survey questions and answer options.

Q1- During the last month, have there been any changes in your dog's health, environment or medication regime?	• Yes (please specify the changes) • No, everything is unchanged
Q2- On average, during the last month, how often did your dog wear the brace on a daily basis?	• Not at all • A few minutes per day • A few hours per day • Almost all day (but not at night) • Almost all day and night
Q3- During the last month, did you adhere to the brace wearing schedule suggested by your veterinarian?	• Yes • No, my dog wore the device more often than recommended • No, my dog wore the device less often than recommended • My veterinarian did not suggest a wearing schedule • Other (please specify)
Q4- Has your dog received any form of rehabilitation (physical therapy) during the last month?	• Yes, our dog had at least one session with a rehabilitation (physical therapy) specialist and we have performed rehabilitation at home • Yes, our dog had at least one session with a rehabilitation (physical therapy) specialist • Yes, we have performed rehabilitation (physical therapy) ourselves at home • No • Other (please specify)
Q5- Overall, during the last month, how much do you think your dog benefited from the brace?	*(Please use the slider below to select how beneficial the brace was for your dog)*
Q6- Overall, during the last month, how active was your dog?	*(Please use the slider below to select your dog's activity level)*
Q7- Overall, during the last month, how happy was your dog?	*(Please use the slider below to select your dog's happiness level)*
Q8- Overall, during the last month, how satisfied are you with the brace as a treatment for your dog's disease?	*(Please use the slider below to select your satisfaction level with the brace)*
Q9- During the last month, have there been any complications (other than skin sores) associated with the brace?	• Yes (please specify the complication/s) • No, everything is fine
Q10- During the last month, did your dog develop any skin sores, skin irritation, or other wounds from wearing the brace?	• Yes • No
Q11- Please describe the skin sore, irritation, or wound.	*Text box*
Q12- Did you have your dog assessed by a veterinarian for the skin sore, irritation, or wound?	• Yes • No • I have not yet, but I plan to • Other (please specify)

All questions were required to be answered by the owners apart from questions 11 and 12, which were only asked of the owner if they reported a skin complication in question 10. Questions 5–8 were answered with a slider bar with available options between 0 and 100.

valid trials were obtained in both directions (six total trials) without lateralization of the head, stepping off the pressure sensitive walkway, or pulling on the leash. A trial was also deemed invalid if the patient would not utilize the affected limb (was non-weight bearing), as kinematic variables of the non-weight bearing limb would not be able to be assessed (15). If the patient was only compliant walking in one direction at baseline, the trials were only obtained walking in that direction at all follow-up visits. The trials were only considered valid if the velocity of the dog was within 0.3 m/s of the previous trials. The video recorded during the gait analysis data collection was reviewed to ensure that the program had appropriately labeled each foot placement.

Percent body weight distribution (%BW) of the limb fitted with the VOP was calculated by dividing the peak vertical force of the limb fitted with the VOP by the peak vertical force of all four limbs throughout the gait cycle and multiplying that number by 100 (16). The %BW was then averaged from the six valid trials. If six valid trials were unable to be obtained due to patient compliance, the average of the valid trials was calculated. If the patient had bilateral devices, %BW was recorded for both affected limbs and included in statistical analysis, regardless of when the devices were fitted. Improvement of %BW was defined as any increase in %BW on the limb fitted with the VOP.

For orthoses patients, OGA was collected both with and without the device donned. OGA trials without the device donned were only collected in patients with orthopedic injuries that would not be harmed by the patient ambulating without the device.

Statistical analysis

For statistical analysis, CSOM and OGA data from the baseline visit and most recent follow-up visit available for each patient was utilized. If the patient did not have a baseline CSOM or any follow-up CSOM questionnaires, they were excluded from CSOM data analysis. Only patients with both baseline and follow-up data for OGA (with and/or without the device donned) were included in %BW data analysis.

If an owner reported, or the examining veterinarian identified, the development of a comorbidity unrelated to device use and this comorbidity was determined to likely affect the patient clinically, the data for the affected variables were not included in data analysis. If the comorbidity was temporary, the data was only omitted from analysis for the times during which the comorbidity was present.

The available online survey data was evaluated for instances of complications throughout the 12 months and types of complications were recorded. The skin complications were analyzed in two groups, those occurring within the first 3 months of the study and those occurring between months 4 and 12.

For statistical analysis of complications, the sore severity category "unknown" was included in the minor category. Analysis was performed based on individual patients as opposed to each instance of skin complication. If a patient experienced at least one major skin complication, they were analyzed within the major skin complication group, otherwise they were analyzed within the minor skin complication group.

Following completion of data collection, patients were divided into four major device groups for statistical analysis. These included patients with a carpal orthosis (CO), patients with a stifle orthosis (SO), patients with a tarsal orthosis (TO), and patients with a prosthetic device (PD). The data from patients who did not fall within one of these four device groups were not included in the statistical analysis.

Fisher's Exact test was utilized to determine associations between categorical variables, including percent of owners discontinuing use of device with device group, patient non-acceptance with device group, patient non-acceptance with discontinuation of the device, mechanical device problems with device group, skin complications in the first 3 months with device group, skin complications between 4 and 12 months with device group, sore severity (for both first 3 months and between months 4 and 12 months) with device group, and whether a veterinary evaluation occurred with sore severity (for both first 3 months and between 4 and 12 months). Fisher's Exact test was utilized due to small counts in some categories. Spearman correlation was used, due to non-normally distributed data, to determine the association between the number of skin complications and the number of veterinary evaluations reported by the owners in the survey specifically for these skin complications. The Kruskal–Wallis test was used to determine if there was a difference between device categories in terms of number of mechanical device failures. A one-way ANOVA F-test was used for comparison of differences in %BW and CSOM scores between device categories. When the F-test revealed a $p < 0.05$, Tukey adjusted pairwise comparisons were performed.

Results

Sixty-one patients were enrolled in the study and 43 patients with at least the first 3 months of complete online surveys were included for analysis of all available data (Table 2). Fourteen patients were fitted with stifle orthoses, with one patient fitted for two stifle orthoses ~6 months apart, resulting in 15 SO analyzed. The remaining categories included 10 CO, 10 TO, and 7 PD. One patient was fitted with a forelimb device for partial brachial plexus avulsion and did not fall into the four major device categories. All SO were prescribed for treatment of cranial cruciate ligament disease (CCLD). Five out of 10 (50%) CO were prescribed for treatment of carpal hyperextension. The other CO were prescribed for various conditions including carpal instability, carpometacarpal instability, deep digital flexor myotendinopathy, antebrachiocarpal luxation, and digital hyperextension. Six out of 10 (60%) TO were prescribed for treatment of common calcanean tendinopathy. The other TO were prescribed for various conditions including tarsal

TABLE 2 Patient signalment, diagnosis, and device group.

No	Breed	Age (years)	Sex	Diagnosis	Device group
1	Australian Shepherd	6	MC	Brachial plexus avulsion	Full forelimb orthotic device
2	Australian Cattle Dog	1	FS	Antebrachiocarpal luxation	CO
3	Border Collie	9	MC	Deep digital flexor myotendinopathy	CO
4	Australian Shepherd	6	MI	Carpal instability	CO
5	Anatolian Shepherd	9	MC	Digital hyperextension	CO
6	Mixed Breed	6	FS	Lateral carpometacarpal instability	CO
7	Labrador Retriever	11	MI	Carpal hyperextension	CO
8	Mixed Breed	7	FS	Carpal hyperextension	CO
9	Mixed Breed	7	MC	Carpal hyperextension	CO
10	Border Collie	10	MC	Carpal hyperextension	CO
11	German Shepherd	12	FI	Carpal hyperextension	CO
12	Standard Poodle	8	MC	Cranial Cruciate Ligament Disease	SO
13	Standard Poodle	8	MC	Cranial Cruciate Ligament Disease	SO
14	Staffordshire Terrier	9	FS	Cranial Cruciate Ligament Disease	SO
15	Great Pyrenees	5	MC	Cranial Cruciate Ligament Disease	SO
16	Mixed Breed	9	FS	Cranial Cruciate Ligament Disease	SO
17	Mixed Breed	5	MC	Cranial Cruciate Ligament Disease	SO
18	Golden Retriever	9	FS	Cranial Cruciate Ligament Disease	SO
19	Mixed Breed	8	MC	Cranial Cruciate Ligament Disease	SO
20	St. Bernard	6	FS	Cranial Cruciate Ligament Disease	SO
21	Staffordshire Terrier	7	FS	Cranial Cruciate Ligament Disease	SO
22	Mixed Breed	7	FS	Cranial Cruciate Ligament Disease	SO
23	Golden Retriever	13	FS	Cranial Cruciate Ligament Disease	SO
24	Catahoula Leopard Dog	12	FS	Cranial Cruciate Ligament Disease	SO
25	Labrador Retriever	12	MC	Cranial Cruciate Ligament Disease	SO
26	Mixed Breed	8	FS	Cranial Cruciate Ligament Disease	SO
27	Great Dane	9	FS	Osteosarcoma (amputation)	PD
28	Border Collie	1	MC	Congenital deformity	PD
29	Mixed Breed	1	MC	Missing distal forelimb (unknown if congenital or traumatic)	PD
30	Dachshund	2	MC	Traumatic amputation	PD
31	Labrador Retriever	7	FS	Soft Tissue Sarcoma (amputation)	PD
32	German Shorthaired Pointer	2	FS	Congenital deformity (amputation)	PD
33	Labrador Retriever	2	FS	Amputation secondary to trauma	PD
34	Labrador Retriever	8	FS	Common Calcaneal Tendinopathy	TO
35	Labrador Retriever	10	FS	Common Calcaneal Tendinopathy	TO
36	German Shorthaired Pointer	9	MC	Common Calcaneal Tendinopathy	TO
37	Labrador Retriever	7	MC	Common Calcaneal Tendinopathy*	TO
38	Labrador Retriever	11	FS	Common Calcaneal Tendinopathy	TO
39	Labrador Retriever	7	MC	Common Calcaneal Tendinopathy*	TO
40	Labrador Retriever	7	MC	Tarsal Instability	TO
41	Mixed Breed	2	MI	Postoperative Fracture Fixation	TO
42	Labrador Retriever	8	FS	Medial Collateral Ligament Instability	TO
43	German Shepherd	3	MC	Postoperative digital flexor tendon repair	TO

FS, female spayed; FI, female intact; MC, male castrated; MI, male intact; CO, carpal orthosis; SO, stifle orthosis; PD, prosthetic device; TO, tarsal orthosis.
*Bilateral devices fitted simultaneously.

instability, medial collateral ligament instability, postoperative support for superficial digital flexor tendon repair with deep digital flexor tendon imbrication, and postoperative talar fracture fixation support. Two out of 7 (29%) PD were prescribed

TABLE 3 Explanations and timeline for discontinuation of device use in seven patients prior to veterinary instruction.

Explanation	Device group	Patient number (Table 1)	Month discontinued
Transition to alternate product	CO	5	6
Owner perceived improvement	SO	24	1
Owner perceived improvement	TO	38	6
Mechanical device problems	SO	15	7
Patient non-acceptance	SO	20	10
Comorbidity	SO	23	7
Comorbidity	PD	27	5

following amputation for neoplasia (osteosarcoma and soft tissue sarcoma), 2 out of 7 (29%) were prescribed for congenital defects or following amputation secondary to congenital defects, out of 7 (29%) were prescribed for patients following traumatic amputation or amputation secondary to trauma, and 1 out of 7 (15%) was prescribed for a patient with unknown cause of partially missing limb.

The median number of months of completed online survey responses for all patients was 10, with owners completing online surveys between 3 and 12 months out of 12 possible months. Four patients were unable to complete the study following humane euthanasia, three of which were orthoses patients that were euthanized following the development of disease processes unrelated to the orthopedic condition that resulted in prescription of the device. One postoperative amputation prosthesis patient was euthanized following pulmonary metastasis of osteosarcoma. Two SO became clinical for CCLD in the opposite limb during the study. One SO developed suspected idiopathic vestibular disease, which improved after about 2 months per the owners. One CO developed carpal hyperextension of the opposite limb during the study.

Patients in multiple groups discontinued use of the device prior to veterinarian instruction, including 4 out of 15 (27%) SO, 1 out of 10 (10%) CO, 1 out of 10 (10%) TO, and 1 out of 7 (15%) PD (Table 3). Explanations for discontinuation of use included owner-perceived improvement, mechanical device problems, patient non-acceptance of device, transition to an alternate product, or development of a comorbidity eliminating activities requiring the device or affecting use of the device. There was no evidence of an association between device group and proportion of patients who stopped wearing the device prior to veterinary instruction ($p = 0.76$).

Thirty-nine out of 43 (91%) patients experienced at least one complication (skin complication, mechanical problem, and/or patient non-acceptance of device), with 7/7 (100%) prosthesis patients experiencing at least one complication. At least one skin complication was reported for 8 out of 14 (58%) SO, 9 out of 10 (90%) CO, 6 of 10 (60%) TO, and 4 out of 7 (58%) PD during the first 3 months of use (Table 4). There was no evidence of an association between device group and proportion of patients with reported skin complications in the first 3 months ($p = 0.3283$). Twenty out of 41 (49%) patients experienced only minor skin complications in the first 3 months, while 7 out of 41 (17%) patients experienced at least one major skin complication (Table 5). There was no evidence of an association between severity of skin complications and device group ($p = 0.1063$). There was also no evidence of association between severity and seeking an evaluation by a veterinarian for the skin complication in the first 3 months ($p = 0.2040$). There was evidence of a moderate correlation between number of skin complications in the first 3 months and the number of evaluations by a veterinarian for the skin complication ($r = 0.59$, $p = 0.0013$).

At least one skin complication was reported for 8 of 13 (62%) SO, 5 of 10 (50%) CO, 2 of 9 (23%) TO, and 3 of 7 (43%) PD between months 4 and 12 after fitting (Table 4). There was no evidence of an association between device group and proportion of patients with reported skin complications in those months ($p = 0.3607$). Sixteen out of 39 (41%) of patients experienced only minor skin complications between months 4 and 12 after fitting, while 5 out of 39 (13%) patients experienced at least one major skin complication in those months. There was no evidence of an association between severity of skin complications and device group ($p = 0.7354$). There was no evidence of an association

TABLE 4 Percentage of patients experiencing at least one skin complication by device group.

Device group	First 3 months	Months 4 and 12
SO	58% (8/14)	62% (8/13)
CO	90% (9/10)	50% (5/10)
TO	60% (6/10)	23% (2/9)
PD	58% (4/7)	43% (3/7)
Total	66% (27/41)	46% (18/39)

TABLE 5 Skin complication severity by device group in first 3 months.

Device group	Minor	Major	Total
SO	6	2	8
CO	8	1	9
TO	2	4	6
PD	4	0	4
Total	20	7	27

between skin complication severity and seeking an evaluation by a veterinarian for the skin complication between months 4 and 12 ($p = 1$). There was no evidence of a significant correlation between number of skin complications between months 4 and 12 and the number of evaluations by a veterinarian for the skin complication ($r = 0.33$, $p = 0.1436$).

Eleven owners reported mechanical device problems (Table 6), which included minor problems such as screws coming loose, expected wear and tear of replaceable items such as the hook and loop tape, tread, and padding, and various device components coming detached. These problems required repair by the owner, the prescribing veterinarian, or manufacturing company (depending on extent of damage) at least once, with seven owners reporting mechanical device problems between 2 and 4 times. One out of 15 (7%) SO, 4 out of 10 (40%) CO, 4 out of 10 (40%) TO, and 1 out of 7 (15%) PD experienced mechanical device problems. The full forelimb orthotic device also experienced mechanical device problems. There was no evidence of an association found between device group and mechanical device problems ($p = 0.1110$). There was also no evidence of a difference in device groups in number of mechanical problems reported ($p = 0.1288$).

Seven patients were non-accepting of their device, as indicated by owner reports of the patient chewing on the device, resistance to device application, or refusal to utilize the limb with the device donned (Table 7). Non-acceptance of the device was identified with 2 out of 15 (14%) SO, 1 out of 10 (10%) TO, and 4 out of 7 (55%) PD. Non-acceptance was not reported with CO. There was evidence of an association between device group and lack of device acceptance ($p = 0.0179$), with PD having the highest rate of non-acceptance. There was no association between patient non-acceptance and no longer using the device ($p = 0.3178$).

Objective gait analysis at baseline and follow-up with the device donned and doffed were performed on all patients in which it was clinically appropriate and would not exacerbate their condition gaiting sans device. With the device donned (67%), of CO showed improvement, 8 out of 8 (100%) of SO showed improvement, 10 out of 10 (100%) of TO showed improvement, and one out of 1 (100%) of PD showed improvement in %BW of the affected limb between baseline and the most recent follow-up. All other patients had a lower %BW of the affected limb with the device donned. On average, SO showed an increase in 4.0%BW ± 3.1% ($n = 8$; percent increase of 51.6% ± 77%), CO showed an increase in 2.5%BW ± 5.9% ($n = 7$; percent increase of 10.8% ± 30%), TO showed an increase in 3.2%BW ± 2.0% ($n = 8$; percent increase of 22.2% ± 17.1%), and PD showed an increase in 2.9%BW ($n = 1$; percent increase of 34.3%) of the affected limb with the device donned between baseline and the most recent follow-up in patients for which OGA data was available (Table 8). There was no evidence of a difference in device groups for magnitude of change in %BW with the device donned ($F = 0.18$, $p = 0.9116$).

Without the device donned, 5 out of 6 (83%) of CO showed improvement, 11 out of 11 (100%) of SO showed improvement, and 0 out of 4 (0%) of TO showed improvement in %BW of the affected limb between baseline and the most recent follow-up. All other patients had a lower %BW of the affected limb without the device donned. On average, SO showed an increase in 4.0%BW ± 2.0% ($n = 11$; percent increase of 35.1% ± 27.6%), CO showed an increase in 3.4%BW ± 2.8% ($n = 6$; percent increase of 13.9% ± 13%), and TO showed a decrease in 2.3%BW ± 2.2% ($n = 3$; percent decrease of 12.9% ± 7.5%) on the affected limb without the device donned between baseline and the most recent follow-up in patients for which OGA was available (Table 9). There was evidence of a difference in device groups for change in %BW without the device ($F = 8.74$, $p = 0.0024$). Specifically, the change in %BW of TO was different from both SO ($p = 0.0019$) and CO ($p = 0.0085$) without the device donned. Moreover, SO and CO did not show evidence of a difference without the device donned when compared to each other ($p = 0.8621$).

For CSOM scoring, improvements were seen on average across device types from baseline; SO showed an average decrease in score of 1.3 ± 0.70 ($n = 8$) with a percent decrease of 45% ± 30%, CO showed a decrease of 1.0 ± 1.11 ($n = 7$) with a percent decrease of 61% ± 35%, TO showed a decrease of 0.6 ±0.96 ($n = 8$) with a percent decrease of 36% ± 42%, and PD showed a decrease of 1.7 ± 0.79 ($n = 5$) with a percent decrease of 61% ± 33%. There was no evidence of a difference in device groups for change in CSOM score ($F = 1.75$, $p = 0.1836$).

TABLE 6 Mechanical problems by device group and average number of times reported (among those reporting mechanical device problems).

Device experiencing mechanical problems	Average number of times reported
Full forelimb orthotic device	4
SO	1
CO	2
TO	1.5
PD	2

TABLE 7 Non-acceptance types by patient group.

Non-acceptance type	Number of SO	Number of CO	Number of TO	Number of PD
Chewing on device	1	0	1	0
Resistance to device application	1	0	0	2
Refusal to utilize limb	0	0	0	2

TABLE 8 Change in percent body weight distribution of the affected limb between baseline and most recent follow-up with device donned.

Device group	Number of patients	Mean change in %BW (%)	Standard deviation (%)	Minimum (%)	Median (%)	Maximum (%)	Median most recent follow-up visit (months)
SO	8	4.04	3.90	0.57	1.84	11.12	7
CO	6	2.48	5.90	−5.82	3.18	10.61	6
TO	8	3.23	2.04	1.21	2.55	7.47	6
PD	1	2.87	0	2.87	2.87	2.87	7

TABLE 9 Change in percent body weight distribution of the affected limb between baseline and most recent follow-up without device donned.

Device group	Number of patients	Mean change in %BW (%)	Standard deviation (%)	Minimum (%)	Median (%)	Maximum (%)	Median most recent follow-up visit (months)
SO	11	3.98	2.05	1.29	3.9	9.1	12
CO	6	3.37	2.84	−1.59	3.83	6.79	9
TO	3	−2.28*	2.18	−4.78	−1.28	−0.77	12

*$p < 0.05$ compared to other device groups.

Discussion

The primary goal of this study was to prospectively determine complications associated with orthosis and prosthesis use in canine patients. The following three major groups of complications were identified: Skin complications, mechanical device problems, and lack of device acceptance by the patient. We found that skin complications were the most common problem, with more than half of patients in all device groups experiencing at least one skin complication in the first 3 months.

The high rate of skin complications observed is consistent with the high rate observed with casting (17). However, severe skin complications made up the minority of those described in this study. This is likely due to the early detection of sores by owners since the devices are removed at least daily. However, even minor skin complications can disrupt device use while the skin heals, reducing the amount of time the patient can spend in the device. All orthosis and prosthesis patients at the CSU-VTH, including those in this study, are instructed to follow a "break-in" schedule in an attempt to reduce skin complication occurrence. This schedule involves a slow escalation in the number of hours the patient wears the device per day over the course of several weeks. This is obviously only feasible if the patient is not required to wear the device throughout the day for 24 h, e.g., for postoperative support of a tendon repair. Skin complications may occur, despite this break-in period, due to lack of owner compliance with the prescribed schedule, ineffectiveness of the prescribed schedule, the device not fitting appropriately to the limb, owners not applying the device to the limb correctly, owners not appropriately exercise-restricting patients, or simply because the skin is unable to tolerate the applied forces. Owner education may be utilized to improve owner application of the device, including providing personal instructional videos of how to apply the device and providing guide marks on the device as to appropriate tightness of device straps. This strategy was employed in the majority of the cases. Further investigation of novel materials that can reduce complications and improve fit to attenuate device-associated skin complications is warranted.

Based on the authors' clinical experience and the previously published data, skin complications (including abrasions, open sores, loss of hair, etc.) are most likely to occur during the first 2 to 3 months following device fitting (3). This informed the criteria of making completion of the first 3 months of online surveys an inclusion criterion for data analysis, as well as analysis of the sores in two groups (first 3 months and between months 4 and 12). The proportion of patients experiencing skin complications during months 4 through 12 decreased from the first 3 months in all device groups, except for SO. The cause of SO skin complications increasing after the first 3 months is unknown, but may be due to confounding variables, such as increased patient activity level.

The present study is consistent with the previous studies of VOP, as they have also described high proportions of skin complications. In a study by Hart et al., 46% of canines wearing stifle orthoses developed skin lesions (5). Wendland et al. showed a short-term prosthetic-associated complication rate of 61.7% with skin sores being the most common complication, followed by pain, swelling, and dermatitis. The long-term complication rate in that study was 19.1%, with skin sores again being the most common, followed by pain and dermatitis (3). The higher proportion of reported skin complications in the present study compared to the previous studies may be due to the prospective nature of data collection, resulting in improved accuracy of owner reporting or due to smaller sample size of this study.

The association of number of skin complications with evaluations by a veterinarian in the first 3 months may indicate to prescribing veterinarians that there will likely be additional necessary rechecks within the first 3 months of device use. The lack of association of number of skin complications with evaluations by a veterinarian between months 4 and 12 may indicate that the number of additional rechecks can decrease after the first 3 months.

The second most common complication was mechanical device issues. These instances often required repair by the veterinarians at the CSU-VTH or being sent to the manufacturer for more extensive repairs. In case of the latter, the patient was unable to utilize the device until it was shipped back. Wendland et al. found that owner satisfaction and clinical outcome scores were positively correlated with time spent in the prosthesis (3). This may indicate that mechanical device issues, in turn resulting in decreased wear by the patient, may impact both patient's clinical improvement and owner satisfaction. It is important for veterinarians to be aware of this possible complication so that owners can be prepared prior to proceeding with this treatment option. Particularly for dogs that would clinically deteriorate without their device, two devices on hand may also be recommended. This solution may be particularly relevant for patients that are expected to wear the device life-long and clinically appear to benefit from the device (e.g., prostheses).

Prosthetic device (PD) appeared to experience mechanical device issues less often than any of the orthoses. The reason for this lower rate is unknown. However, it may be possible that a lower number of articulating portions may be a contributing factor.

The third most common complication was patients not accepting the device. This was most common among PD, with patients most commonly not using the limb and walking on their three remaining legs or being resistant to device donning. Refusal to use the prosthetic limb may be related to patient acclimation to a 3-legged gait over time. However, no significant correlation has been drawn between time from limb loss to prosthesis placement and clinical outcome (3). Patient non-compliance with prostheses may also be related to the level of the defect. The level of the defect has been suggested to contribute to limitations in planes of motion and proprioceptive feedback (3). In this study, PD that did not accept their device had varying levels of defects with the most distal at the level of the mid-metatarsus. However, the small sample size of PD precludes drawing conclusions as to whether a relationship exists between level of the defect and patient non-compliance. Physical rehabilitation may be utilized to encourage use of the limb starting with habituating the patient to weight bearing and eventually improving patient proprioception and balance with the limb donned (1, 18). Studies in humans have shown improved clinical outcomes associated with rehabilitation following prothesis fitting (19). However, no positive correlation has yet been established in canine patients (3). Lack of device acceptance was not demonstrated in the canine retrospective series or in a study of four cats with ITAP (12, 20). It is possible that endoprostheses are superior to socket prosthesis in terms of device acceptance, but further research is required to adequately compare these two options.

Of the three patients wearing orthoses that were non-accepting of the device, two were reportedly chewing on their devices (one from the SO group and one from the TO group), with one resulting in mechanical device issues requiring repair. These did not appear to be solely connected to patient acclimation to the device in this study, as destruction with one patient occurred during the first month of wear, while the other occurred during the seventh month of wear. Patient destruction of the device may be addressed by only donning the device when owner supervision is available. However, this would likely decrease time spent in the device, which may result in a decreased clinical improvement and owner satisfaction.

The third patient that did not accept the device was in the SO group. This patient was resistant to device donning and refused to stand or ambulate following device donning. This behavior began during the sixth month of wearing the orthosis and continued through the twelfth month. Physical rehabilitation and positive reinforcement training may be methods of addressing this complication, but no data was collected regarding response to interventions for the patient in this study.

It is important for veterinarians to be aware of these three possible major complications, given the high incidence, in order to adequately educate clients. The potential consequences and resolutions of these complications, such as additional veterinary evaluations, device repairs, physical rehabilitation, and/or obtaining a backup device, will increase the total cost of treatment. Hart et al. showed that financial considerations were the third-most cited reason for pursuing a stifle orthosis over surgical intervention (2). Therefore, it is imperative that owners be aware of the potential financial implications of these complications prior to electing to use orthoses or prostheses as a treatment option.

Moreover, it may be indicated for veterinarians to discuss discontinuation of the device in cases where animals are not accepting of the device, especially in cases where the patient is severely resistant to device application. Interestingly, there was no association between patient non-acceptance of the device and owners discontinuing device use prior to veterinary instruction in this study. Only one owner cited patient non-acceptance of the device as the reason for entirely discontinuing use. One owner with a patient who was non-accepting of the device discontinued use but cited the development of bursitis as the reason for discontinuing use. This may indicate that owners are reluctant to discontinue treatment in cases of non-acceptance and the quality of life of the animal may need to be assessed. Additionally, patient chewing of the device may pose a safety risk if pieces of the device are ingested and cause a gastrointestinal mechanical obstruction.

As the outcome parameter for gait analysis, %BW was chosen since Kano et al. showed that %BW was most accurate of kinetic and temporospatial gait parameters within a heterogenous group of dogs when gait velocity is controlled for (16). The observed improvement in %BW with the device donned may indicate that the use of these devices provided a benefit to the patients' diseases or alternatively simply patient acclimation to the device. Conzemius et al. suggest a 5% improvement in ground reaction forces as a guideline for what can be considered clinically important in dogs with osteoarthritis (15). While the patient population studied differs from this proposed guideline, the data support a possible beneficial effect on the disease process given that the average improvement (percent increase) in %BW was >5% in all groups with the device donned. The SO and CO groups also showed a >5% improvement without the device donned in patients for which OGA data was available, which supports a beneficial effect on the disease process. In contrast, the TO group showed a negative change in %BW without the device in patients for which OGA data was available. The differences in change of %BW with the device donned and without may also be explained by alterations in ground force reaction caused by immobilization created by the device. A study by Murakami et al. showed that the level of constraint created by device affects the ground reaction force pattern (21). Additionally, Torres et al. showed that the application of a stifle orthosis affected the kinematics for all joints and planes of motion at a walk and trot (22). This may specifically explain the noteworthy discrepancy between the improvement in TO with the device donned and without, as the tarsal devices induced a variable level of constraint based on the injury. Overall, it is worthwhile noting that there is a lack of knowledge regarding interpretation of ground reaction forces in patients with VOP devices with varying underlying pathology and this data should therefore be interpreted with caution.

This study is not able to attribute improvements in %BW to the use of the orthoses, as there were no control groups associated with each device. Similar improvement may have occurred over time in many of these patients regardless of device use. A study by Wucherer et al., for example, showed that 64% of overweight CCLD patients managed with pain medication, weight loss, and physical therapy alone showed improved quality of life and lameness after 1 year (23). There have been no studies evaluating outcome of orthoses that have utilized control groups to establish significant improvement in limb function in animals fitted with devices compared to animals not fitted with devices (4, 7, 8). Thus, the attributable benefit of these devices compared to medical management without these devices is not known.

This differs from the ability to attribute improvements in %BW with prostheses, as %BW for the affected limb without the device is generally 0, other than cases where the degree limb length discrepancy is mild, and the limb contacts the ground. Thus, any improvement in %BW from baseline to follow-up would be attributable to device use by the patient. However, data for change in %BW was only obtained for one dog in the PD group with the device donned. This was primarily due to PD non-acceptance with utilizing the limb immediately following fitting resulting in a lack of baseline data. There was one recorded instance of the patient using their prosthesis for OGA at follow up visits following non-acceptance at fitting. However, there may have been instances that were missed as OGA was not attempted at follow-up visits in multiple PD where baseline data was not obtained.

In many CO and TO, it was determined to not be allowable for the patient to ambulate without the device in place, limiting both baseline and follow-up data collection without the device donned. For patients whose owners discontinued use of the device prior to veterinary instruction, follow-up OGA data was not able to be obtained with the device donned. This is useful in consideration for design of possible future VOP studies, as OGA data collection can be limited by these particulars.

On average, patients in all device groups showed improvement of CSOM score, indicating perceived clinical improvement in patient activities by the owner. It is important to note that the CSOM is not currently validated for use in canine patients with orthoses or prostheses. Additionally, the CSOM typically involves owners selecting patient behaviors to grade in addition to activities (13). Owners were not asked to grade behaviors in this study, as patients' behaviors were expected to change with the application of the device. However, the owners selected activities common in the patient's life, such as ability to climb stairs or ability to play with other dogs without lameness. Despite not being validated for this purpose, improvement in the CSOM score still indicates that, on average, patients were able to resume activities with decreased difficulty as perceived by the owner. It is also important to note that there was no control group, as such it is difficult to interpret owner perception (e.g., how much of the improvement is attributable to caregiver placebo effect).

There are several limitations associated with this study when it comes to the outcome assessment aspect of the study. Most importantly, as noted above, there were no control groups and injuries varied within all device groups, except for SO. Many patients received adjunctive medical therapies as prescribed by the veterinarians at the CSU-VTH, including physical therapy, shockwave therapy, joint injections, and others. Moreover, device use was not measured objectively and was inconsistent among the patients throughout the study. Thus, it is unknown whether the degree of clinical improvement can be attributed to the device or to the other treatments or time alone.

The residual limbs of PD were not uniform; amputations for patients were not performed using a standardized approach, patients had a variety of congenital anatomic defects, one patient had a traumatic amputation, and the history of one patient was unknown. The variability in residual limbs may have confounded patient improvement measures. Additionally, there were no inclusion criteria regarding patient breed or size. Thus, patient conformation may have introduced another confounding variable to our analysis.

The sample sizes were also small within each device group, despite 2 years of enrollment in the study. The sample sizes for OGA collection were reduced further due to censorship and the OGA clinical considerations with devices described above. The small sample sizes limited the power associated with our analysis, which reduced the probability of detecting true differences.

The online survey was developed by the authors and was not pilot tested, and thus was not validated prior to initiation of the study. The survey data provided information regarding complications but was likely subject to both response bias and non-response bias. Owners were also not asked if they had access to internet prior to enrolling in the study, which may have inadvertently biased recruitment to the study. Additionally, owner descriptions of skin complications were utilized to create the scoring system, with several responses labeled "unknown" due to lack of clear description. Owners were not provided with specific training in the categorization of complications, which likely contributed to the lack of clear descriptions and potentially increased the subjectiveness of the skin complication severity. The resulting scoring system was also subjective, despite two of the authors agreeing on scores for the provided descriptions. Due to the existence of the "unknown" label and the inability to determine the severity of these skin complications compared to those in the minor severity category, these categories were grouped together, which may not be an accurate representation of the true severity of the skin complications, as the "unknown" skin complication may have been more severe than those in the minor severity category. The reporting of the skin complications furthermore relied on each owner to detect these complications, which may have resulted in missed skin lesions and artificially low skin complications reported by less attentive owners.

Not all follow-up visits were utilized in data analysis, which may have resulted in missed trends in patient improvement or progressive lameness. This approach was selected due to the study's focus on long-term improvement and acclimation. In addition, the number and timing of follow-up visits were variable due to disturbance to clinical practice associated with COVID-19 pandemic restrictions and that several animals were euthanized prior to the completion of the study. Thus, the most recent follow-up visits occurred at different timepoints for various animals, ranging between 3 and 15 months. This resulted in the comparison of patient improvement at different stages in their disease process.

Further studies of each device with larger sample sizes and control groups are needed to objectively quantify whether these devices significantly improve lameness severity. Additionally, further studies are necessary to determine the specific implications of patient conformation with VOP. However, this study is the first that provides prospective data regarding complications and potential therapeutic benefit that can be utilized in daily clinical practice in the prescription of these devices.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The animal study was reviewed and approved by the Animal Care and Use Committee and Clinical Review Board of Colorado State University. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

SR and FD contributed to the conception and design of the study. SR created the initial online survey, which was revised and edited by FD. SR organized the data and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

Author FD is a paid consultant of OrthoPets, LLC. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.892662/full#supplementary-material

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Case study: Treating infraspinatus and supraspinatus trigger points and supraspinatus tendinopathy utilizing piezoelectric shockwave

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Two individual case studies demonstrate piezoelectric shockwave treatment for the resolution of a supraspinatus tendinopathy and supraspinatus and infraspinatus myofascial trigger points (MTPs) *via* musculoskeletal ultrasound. This is the first documentation of improvement of both tendon and muscle fiber patterns in canine patients treated with piezoelectric shockwave. These cases validate the use of piezoelectric shockwave during the rehabilitation of common canine shoulder injuries.

KEYWORDS

piezoelectric shockwave, musculoskeletal ultrasound, supraspinatus, infraspinatus, myofascial trigger points

Introduction

Injuries of the canine shoulder are commonly seen in active large-breed dogs (1–3). The following two cases, with both tendon damage to the supraspinatus muscular tendon junction and myofascial trigger points (MTPs) within the supraspinatus and infraspinatus muscles, demonstrate resolution by utilizing a piezoelectric shockwave. There are previous reports of canine shoulder tendinopathies treated with electrohydraulic shockwave (4, 5). However, these are the first cases with both injuries to the supraspinatus tendon and MTPs in the supraspinatus and infraspinatus muscles treated with piezoelectric shockwave and having ultrasound images showing improved fiber pattern.

Myofascial trigger points are hyper-irritable spots located in a taut band of skeletal muscle at the level of the motor endplate and the sarcoplasmic reticula. They can generate pain and dysfunction and are often caused by mechanical stresses resulting in chronic muscle overload. This results in localized hypoxia and ischemia and the release of inflammatory mediators, which sensitize afferent nerve fibers accounting for the tenderness of the area (6–9). Originally, the only way to visualize a MTP was through MRI. Musculoskeletal ultrasound allows for the visualization of normal and abnormal muscle fiber patterns and is now being used along with palpation skills to identify MTPs (10–14). Utilizing musculoskeletal ultrasound allows for the objective assessment of the resolution of MTPs. Tendinitis can accompany MTPs or can be independent and it occurs most commonly in dogs from repetitive injury or from an acute injury. Musculoskeletal ultrasound has been a way to evaluate tendon structures for fiber damage (10–14). The additional use of musculoskeletal ultrasound to visualize the resolution of MTPs is very useful for the relationship of damaged tissue to pain function of canine patients who cannot communicate *via* human language (15–19).

In human medicine, shockwave had been documented as a useful therapy for both tendon injuries and MTPs. However, in canine patients, shockwave has primarily been used for orthopedic injuries involving bone, tendon, and ligament damage (4, 5, 20–23). Shockwaves are produced by a single pulse high-pressure wave, up to and above 100 MPa. A short rise time and steep slope that occurs in nanoseconds followed by negative pressure, low tensile wave with a small pulse width, both pressure waves occur over about 5–10 µs (24, 25). The Shockwave mechanism of action is well understood as it has been shown to stimulate new blood vessel formation, regulate inflammation, release nitrogen monoxide (NO) that contributes to vasodilation, increase metabolic activity and angiogenesis, and exert an anti-inflammatory effect (26–29). It changes the level of substance P, stimulates bone metabolism, and releases growth factors: IGF, TGF beta, and VEGF gamma (30–34). In addition, shockwave therapy exhibits chondroprotective effects, allows for the dissolution of calcified fibroblasts, stimulates lubricin production, and also stimulates stem cells (35–38).

Shockwaves can be produced using electromagnetic, electrohydraulic, or piezoelectric generators. Electromagnetic and electrohydraulic shockwave modalities are indirectly focused, while piezoelectric shockwaves create direct focused shockwaves. In the cases presented here, direct focused piezoelectric shockwave, PiezoWave^2-Vet made by Richard Wolf, was chosen as the modality for the treatment of both shoulder tendinopathy and MTPs due to the ability to be precise and deliver pinpoint accuracy of energy. A change in fiber pattern in both the tendon injury and the MTPs was seen *via* musculoskeletal ultrasound after the use of the piezoelectric shockwave and an appropriate rehabilitation plan. This supports *in vitro* and human clinical studies with piezoelectric shockwaves indicating that the therapeutic value of shockwave therapy is independent of the mechanism by which the shockwaves are formed (33, 39–41).

Case 1: 10-year-old, MN, Great Pyrenees mix

Case history

The male dog was presented for coxofemoral degenerative joint disease management when pharmaceuticals were not enough to keep him comfortable. He was slow to rise in the morning and was now limping on the right front limb. The dog was slipping on the hardwood floors at home and refusing to go up the stairs. He continued to go for a 1-mile leash walk daily but was unable to get up on furniture and stopped playing. He was taking gabapentin and carprofen prior to being evaluated.

Initial evaluation

On physical evaluation, the dog had shown decreased hip and shoulder extension. His initial right shoulder extension was 153 degrees, and his left shoulder extension was 153 degrees. He was guarded on right shoulder extension and had MTPs in the right supraspinatus and infraspinatus muscles. There was pain on supraspinatus tendon palpation. Body condition score was seven out of nine and a lameness score of 3/5 RF (42). The pain score was 2/4 according to the Colorado pain score (42, 43). Digital thermography confirmed the physical evaluation findings. Shoulder radiographs were normal.

Musculoskeletal ultrasound images were obtained prior to any treatment being administered. Left supraspinatus fibers near the musculotendinous junction had an irregular fiber pattern, supraspinatus insertional tendinopathy in the right shoulder (Figure 1A). There were also hypoechoic areas and fiber pattern disruption in both the right infraspinatus and left supraspinatus muscles (Figures 2A, 3A). Bilateral infraspinatus and supraspinatus myofascial trigger points were identified using musculoskeletal ultrasound (Figures 2A, 3A, 4A).

Choice of therapy

A piezoelectric shockwave was utilized to treat the MTPs present in the supraspinatus and infraspinatus muscle groups in addition to the inflammation of the right supraspinatus tendon. A 15 mm stand-off pad was utilized and a frequency of eight shocks/s for a total of 1,000 shocks at 0.032 mj/mm^2 for the trigger point and at 0.039 mj/mm^2 for the supraspinatus tendon. Two treatments were needed for the trigger point and four treatments were needed to resolve the tendonitis. After four treatments with the piezoelectric shockwave, the musculoskeletal ultrasound revealed tendon healing and MTP resolution (Figures 1B, 2B, 3B). The supraspinatus and biceps tendon were measured in cross section (Figure 1D). The muscles and tendons were reimaged at 18 weeks post treatment (Figures 2D, 3C). The dog's pain scale decreased to a one out of four on the Colorado pain score and rehabilitation was started to decrease lameness, increase function, and increased range of motion to the shoulder and coxofemoral joints. Land rehabilitation was implemented to strengthen the affected muscles and to address the compensation. In total, four shockwave treatments were performed. Rehabilitation is ongoing at monthly maintenance intervals due to the chronic degenerative joint disease of the coxofemoral joints.

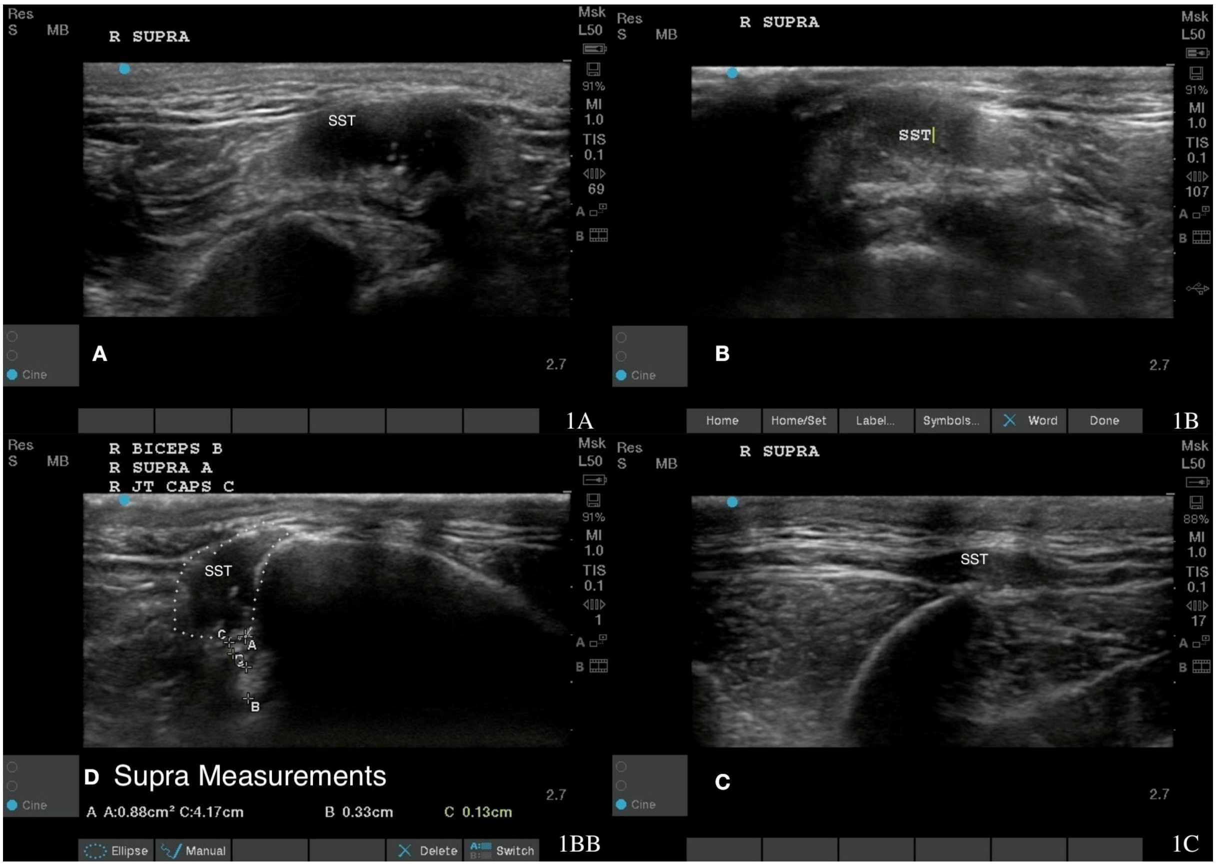

FIGURE 1
Case 1-Right supraspinatus insertional tendinopathy. **(A)** Original image revealing hyperechoic mixed echogenicity within supraspinatus tendon. **(B)** More homogenous tendon fiber pattern is shown at 8 weeks post shockwave therapy. **(C)** A normal fiber pattern is shown at 18 months post shockwave therapy. **(D)** revealed supra measurement at 18 months post shockwave therapy.

Outcome

Rechecks of the dog were performed at 2 weeks and then every 4 weeks until 18 months post treatment. These involved pain assessment, gait analysis, stance analysis, goniometry, Gulick tape measurements, myofascial palpation, digital thermography, and musculoskeletal ultrasounds. Musculoskeletal ultrasound of the supraspinatus tendon and supraspinatus and infraspinatus muscles 8 weeks after starting shockwave therapy revealed a normal fiber pattern of the infraspinatus and supraspinatus muscles, normal echogenicity of the supraspinatus tendon, and a decrease in the overall size of the supraspinatus tendon (Figures 1B,C, 2B,C, 3B,C). At this time, the dog had a lameness score of 1/5 RF. No pain on supraspinatus tendon palpation and right shoulder extension had risen to near normal. The left shoulder extension had increased to 159 degrees and the right shoulder extension had increased to 161 degrees. To date, this dog is 0/5 lame, remains 0/4 on the Colorado pain score, and the owner describes him as back to "acting like a puppy." He is able to run, jump, climb stairs, go for walks, and get up on furniture again. By incorporating a home exercise program, disease-modifying nutraceuticals, and anti-slip flooring and maintenance rehabilitation, this dog has not had any further pain or dysfunction.

Case 2: 9-year-old, male neutered Labrador Retriever

Case history

The male dog presented for limping on his left front limb after he was found at the bottom of a drainage ditch, and was unable to come out. He had tibial-plateau-leveling osteotomy (TPLO) of his left stifle at 5 years of age and TPLO of his right stifle at 2 years of age.

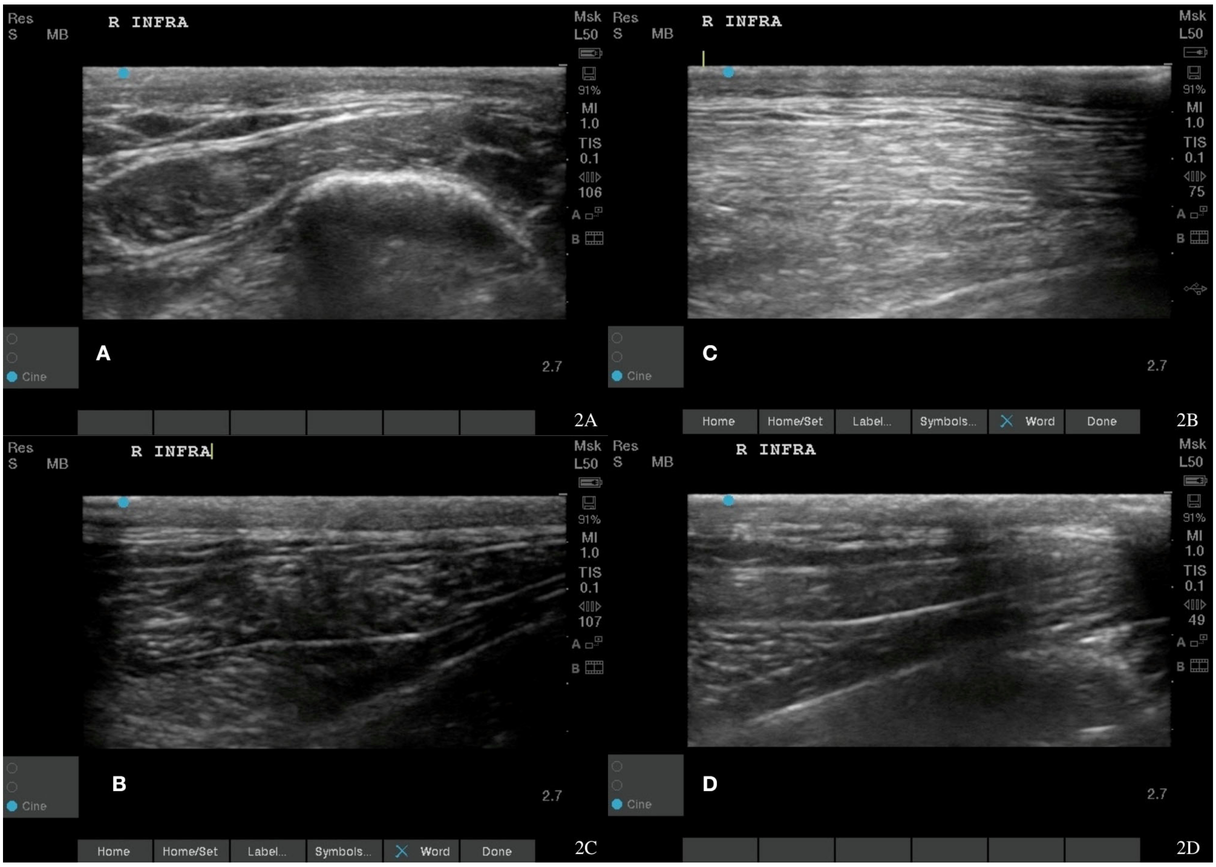

FIGURE 2
Case 1-Right infraspinatus myofascial trigger points (MTPs). **(A)** Original image revealing irregular muscle fiber pattern with hyperechoic and wavy fibers indicating fiber pattern disruption. **(B)** A normalizing muscle fiber pattern is shown at 8 weeks post shockwave therapy. **(C,D)** The normal tendon and muscle fiber patterns are shown at 18 months post shockwave therapy.

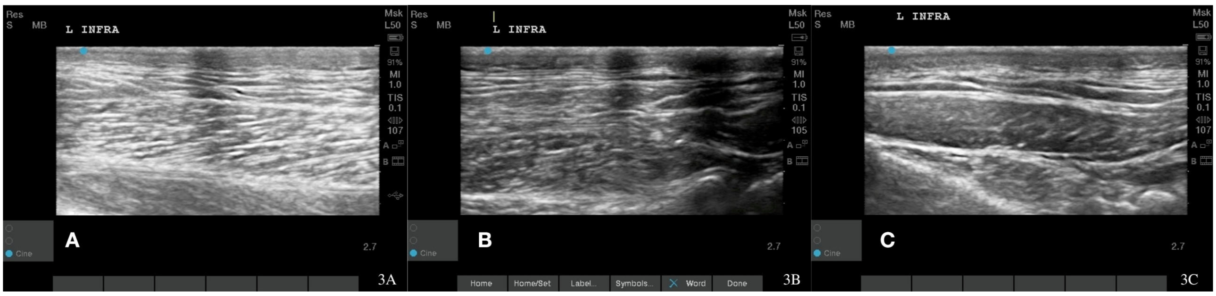

FIGURE 3
Case 1-Left supraspinatus MTP. **(A)** Original image revealing muscle fiber pattern disruption with hypoechoic areas throughout the muscle. **(B)** The wavy muscle fiber patterns with less hypoechoic areas is shown at 8 weeks post shockwave therapy. **(C)** The normal tendon and muscle fiber patterns are shown at 18 months post shockwave therapy.

He has geriatric onset laryngeal paralysis polyneuropathy, laryngeal paralysis, right stifle degenerative joint disease, hyperadrenocorticism, and hypothyroidism. The dog was currently taking carprofen, gabapentin, adequan, and on disease-modifying neutraceuticals.

Initial evaluation

On physical evaluation, the dog had a large MTP near the tendon of insertion on his left infraspinatus. He had pain with full left shoulder extension and full flexion. He had crepitus

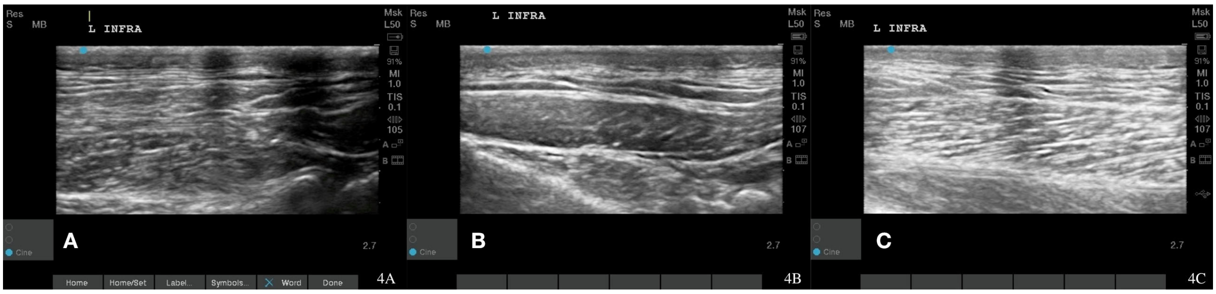

FIGURE 4
Case 1-left infraspinatus MTP. **(A)** Original image revealing irregular muscle fiber pattern. **(B)** A normalizing muscle and tendon fiber pattern is shown at 8 weeks post shockwave therapy. **(C)** Normal muscle and tendon fiber patterns are shown at 18 Month post shockwave reveals.

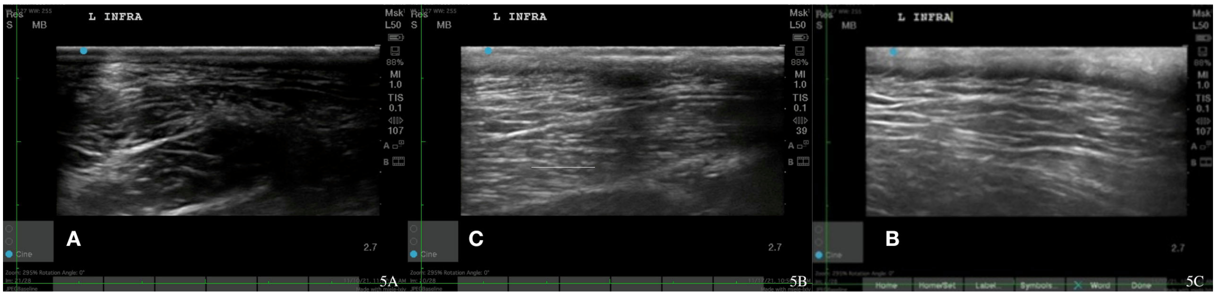

FIGURE 5
Case 2-Left infraspinatus MTP. **(A)** Original injury revealing hypoechoic areas and irregular muscle fiber patterns. **(B)** Myofascial trigger points resolution, 1-week post injury after 2nd shockwave therapy reveals normalizing muscle. **(C)** Follow up, 2 weeks after MTP resolution with normal muscle fiber pattern.

in his left stifle and mild muscle guarding on stifle extension and left and right tarsal valgus secondary to TPLO procedures. His left stifle extension was 144 degrees, and his right stifle extension was 133 degrees. Goniometry was not recorded for his shoulders at this time. His body condition score was seven out of nine and a lameness score of 2/5 LF (42). The pain score was 2/4 according to the Colorado pain score (42, 43). The dog also has mild conscious proprioception deficits in hind limbs due to geriatric onset laryngeal paralysis polyneuropathy. Shoulder radiographs were normal. Musculoskeletal ultrasound images were obtained prior to any treatment administered. Left infraspinatus fibers had an irregular fiber pattern (Figure 5A). Musculoskeletal ultrasound diagnosis was infraspinatus MTPs.

Choice of therapy

The plan for treatment involved four shockwave treatments over the infraspinatus muscle. 145 Piezoelectric shockwave, the Piezowave2-Vet made by Richard Wolf, was utilized to treat the MTP in the left infraspinatus muscle group. A 15 mm linear stand-off pad and a frequency of eight shocks/s for a total of 1,000 shocks at 0.046 mJ/mm^2 were used. In total, four piezoelectric shockwave treatments were performed at a 2x/week interval.

Outcome

After 4 treatments, the musculoskeletal ultrasound revealed the resolution of the MTP (Figure 5B). The patient's pain scale decreased to a score of 1/4 on the Colorado pain score and rehabilitation was started to decrease lameness, increase function, and increase the range of motion to the left-shoulder joint.

After the resolution of the trigger point, land rehabilitation was implemented. Land rehabilitation was utilized to strengthen the affected muscles and address the compensation and address decrease in the range of motion and aid in flexibility and proprioception. Rehabilitation is ongoing at monthly maintenance intervals due to the chronic degenerative joint disease of the left and right stifle joints and concurrent geriatric onset laryngeal paralysis polyneuropathy.

Recheck musculoskeletal ultrasound of the infraspinatus 8 and 12 weeks after starting shockwave therapy revealed a normal fiber pattern of the infraspinatus and supraspinatus muscles

(Figures 3C, 4B,C, 5B,C). Lameness score of 1/5 on right hind remains, and patient resolved lameness on the left front limb. No pain in infraspinatus muscle or tendon palpation or shoulder range of motion. To date, this patient remains 0/4 on the Colorado pain score. The owner describes him as "back to his young self." He continues to run, jump, climb stairs, go for walks, and get up on furniture. He is back to running in the drainage ditches and helping to keep the property free from wildlife. By incorporating a home exercise program, anti-slip flooring, and maintenance rehabilitation, this patient has not had any further pain or dysfunction.

Conclusion

Muscle sprains, tendinopathies, and MTPs are common in practice. How we manage and treat these common occurrences is ever evolving. Incorporating shockwave early in the treatment of these conditions resulted in quicker resolution of pain, faster resolution of lameness and discomfort for the dog, and increased function of the muscles and tendons (3, 4, 7, 20–23, 34, 36). While palpation of the myofascial structures can never be underestimated, being able to "see" the healing with the use of digital thermography and musculoskeletal ultrasound help to give us a more objective analysis of the resolution utilizing different modalities, including piezoelectric shockwave, therapeutic ultrasound, and regenerative medicine, as we work together to further understand how to better treat our patients (10–14, 16, 42).

The piezoelectric shockwave mechanism of action is well understood and used regularly for human therapy medicine (33, 38–41). However, due to being a site specific direct focused shockwave, its efficacy has been questioned in veterinary medicine. MTPs allow for the perfect place to start with evidence to assess how piezoelectric shockwave can be utilized in veterinary medicine. With the understanding that shockwave can be an important part of tendon healing, ligament healing, and osteoarthritis management in animals, more information is needed to evaluate its effect on myofascial trigger points.

With the addition of piezoelectric shockwave and rehabilitation exercises, the following patients were able to keep their muscle and musculocutaneous junction intact and are maintaining function. Historically, it has been documented that tendon damage and MTPs respond to conservative management with manual trigger point release, shockwave, regenerative medicine, rest, and corticosteroid injection into the bursa or tendon (4, 7, 20, 44). However, some patients do require surgical resection and release of the tendon.

These case reports are initial documentation of the ability of piezoelectric shockwave to heal both Canine tendon and muscle injuries containing diagnostic ultrasound images. Tendon injuries are often documented with musculoskeletal ultrasound; however, especially in veterinary medicine, ultrasound images of trigger points and other muscular damage are not as widely available. Advances in musculoskeletal ultrasound techniques are allowing veterinarians to equally image both tendon and muscle fibers to help better determine when appropriate rehabilitation exercise should be implemented.

There are clear limitations in drawing significant conclusions from just two retrospective cases. Prospective, controlled, and clinical studies are needed to make a full comparison of piezo extracorporeal shockwave therapy (ESWT) technology to electrohydraulic technology. However, it is important to recognize there is initial objective data in veterinary medicine supporting the hypothesis that the means by which the shockwave is formed does not have a direct effect on the biological response of the tissue. The appropriate amount of energy and the path of the energy is very important. However, dosing for therapeutic shockwave is a difficult topic that needs to be better understood.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for the animal study because no animal was sedated or injured during these case reports. Owners gave permission to treat. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

Author HO was employed by the company Animal Acupuncture and Canine Sports Medicine Facility, LLC.

Publisher's note

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Physical activity and sport-specific training patterns in Swedish sporting and working trial dogs—A questionnaire survey

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Objective: To explore physical activity patterns, including conditioning exercise and sport-specific training, and management routines utilized by handlers of Swedish sporting and working dogs participating in agility, obedience, rally obedience and working trial disciplines.

Procedures: Dog handlers provided information on competition-level dogs through an internet-based cross-sectional and descriptive survey on physical activity, sport-specific training and management. Results are reported overall and stratified by participation in specific disciplines.

Results: We received 1615 replies to the questionnaire. After data cleaning, 1582 dogs (98%) remained for the analysis. Of these, 430 participated in agility, 790 in obedience, 596 in rally obedience, and 847 dogs had competed in a working trial, i.e., messenger, protection, search or tracking. Number of disciplines performed by each dog varied between one and five. Most common was participation in one ($n = 767$, 48%) or two ($n = 541$, 34%) disciplines. Out of the dogs competing in one discipline, 38% ($n = 294$) were considered to be specialized as they actively trained only that discipline for ≥10 months per year. The vast majority of the dogs ($n = 1129$, 71%) received more than 1 h of daily physical activity, e.g., walks, and only $n = 51$ (3%) were never exercised off-leash. Preferred self-selected gait was trot ($n = 907$, 57%) and gallop ($n = 499$, 32%). A fifth ($n = 319$, 20%) never played with other dogs. The majority ($n = 1328$, 84%) received more than 1 h of vigorous physical conditioning exercise per week. Almost three quarters ($n = 1119$, 71%) participated in physical conditioning exercise. Two thirds ($n = 953$, 60%) participated in at least 3 h of sport-specific training per week and only a very small portion ($n = 35$, 2%) trained their specific discipline less than once per week. Median total work load, i.e., all daily physical activity, vigorous physical conditioning exercise and sport-specific training, was 16.5 h per week.

Conclusion and clinical relevance: We observe physical activity at moderate to high durations and moderate to vigorous intensities among Swedish sporting and working trial dogs. Most dogs received physical conditioning exercise, but not all dogs were warmed up before training and competition. Our study provides veterinary professionals and dog trainers with valuable insights on the physical exposures and management routines of sporting and working trial dogs.

KEYWORDS

physical conditioning, physical activity, sports medicine, sporting dogs, sport specialization, surface, warm-up, working dogs

Introduction

Besides offering companionship, dog sports are popular activities with dogs (1). Furthermore, dog ownership is associated with increased general physical activity in humans (2). Human participants in dog sports have varying backgrounds and purposes, from casual leisure to occupational devotion, and participation is at local to international level (3). Sporting and working trials are becoming popular parts of the canine industry and veterinary professional are regularly treating these dogs in clinic. Therefore, understanding the work load and demands requested from canine athletes is essential for being an effective veterinary professional (4–6). In dog sports, handlers navigate the dogs through physically and mentally demanding tasks, e.g., heelwork, obstacles to overcome, searching for people in the forest and objects to retrieve (4). The physical requirements vary among disciplines, where disciplines such as agility and protection involve tasks that require muscle strength and power, while rally obedience has lower physical impact (4, 7, 8). Other disciplines, like searching and tracking people demand cardiorespiratory and muscular endurance from the dog (9–11).

When participating in sports and working trials, dogs need to be prepared for sport-specific tasks (12–14). Physical fitness, as well as sport and field specific training, are thus integral parts of performance in trials and competitions. Physical fitness includes cardiorespiratory (i.e., aerobic and anaerobic capacity) and neuromuscular (i.e., muscle strength, mobility, balance) components. Body composition (i.e., lean and fat body mass) and nutritional prerequisites, need to be optimized for the dog to reach full athletic performance (15–17).

In the fields of rehabilitation and physical education and training, physical activity and physical conditioning exercises are described according to the "F.I.T.T."-principle (i.e., frequency, intensity, time (duration), and type of exercise) to facilitate exercise prescription (18, 19). Current definitions of canine physical activity are vague. In human literature, physical activity has been recognized as any bodily movement produced by the contraction of skeletal muscles that results in an increase in caloric expenditure over resting energy requirement (19, 20). Physical conditioning exercise is done to improve and/or maintain physical fitness components, and is per definition a type of physical activity consisting of planned, structured, and repetitive bodily movement (13, 15, 19, 20). Sport-specific training in dogs is another type of conditioning, an associative learning process, with regards to learning relevant tasks related to a sport or working discipline (21).

Understanding of how dogs' physical activity patterns are related to their health, well-being, injury and disease in various life stages and performance is increasingly important to canine welfare (22). However, science-based guidelines for achieving health and sport-specific benefits from physical activity in dogs are still sparse. A unified way of reporting physical activity in dogs is essential to facilitate future studies on relationships to canine health and well-being.

Consensus with regards to how to define physical activity patterns in dogs has yet to be established.

The lack of a definition may lead to different procedures to capture and express physical activity in dogs, and even more specifically in working and performing canine athletes. Physical activity pattern can be defined as a way in which physical activities, including physical conditioning exercise, and periodization of sport-specific training are repeated over time (20, 23, 24). A few studies have investigated canine physical activity at various intensities or according to duration (25–28). Durations of physical activity at various intensities have been assessed in privately owned free-ranging dogs, farm dogs, and family dogs by measurements recorded from an accelerometer device (25). Intensity and time-related categories based on canine gaits and duration per day have been described in previous studies. With regards to gait, one study defined walk as light exercise and trot and faster gaits as moderate to vigorous exercise (26), and a second study defined slow walk on a lead as light to moderate activity, and running off leash as vigorous physical activity (27). With regards to time, three time-related categories have been used to describe daily duration of physical activity, i.e., <1 h per day ("low"), 1–3 h per day ("moderate"), and >3 h per day ("high") (29–31).

Although there are several questionnaires validated to measure and monitor levels of physical activity in humans (32), there are no validated owner-reported instruments to capture physical activity and sedentary behaviors in various dog populations. Dog owner-reported measures of physical activity may provide important contextual information (28, 33–40). Hence, estimations of physical activity patterns may be based on subjective means (32, 41), e.g., owner-reported questionnaires (28), owner-reported logs and direct observation, and/or be based on measurements from an objective device, e.g., accelerometer (42, 43), pedometer (44–46), heart rate monitor (47) or smart devices (48, 49).

Recently, several studies have been published on daily physical activity and sport-specific training parameters and their associations to injury in agility dogs (33–35, 39, 40, 50–54). There is however a lack of research focusing on physical activity patterns in sporting and working trial dogs from other disciplines. Canine sporting competitions and working dog trials have been organized by the Swedish Working Dog Association (SWDA) since 1918 (55, 56). The SWDA is a non-profit members' association organized under the Fédération Cynologique Internationale (FCI), the world governing body for canine sporting disciplines (57). The implementation of sporting and working trial disciplines are similar in many countries and international competitions under the same rules are applied, e.g., in obedience classes.

The objective of this study was to explore physical activity patterns, including physical conditioning exercise and sport-specific training, and management routines among sporting and working trial dogs participating in various disciplines in Sweden.

Materials and methods

Dogs and data collection

This research was an online survey with a cross-sectional and descriptive study design. Data were collected for eligible dogs via a questionnaire distributed electronically to handlers of dogs competing in agility, obedience, rally obedience, mondioring, working trials (i.e., messenger, patrol, protection, search, tracking, International Utility Dog trials, International Nordics Style and BH-VT exams) organized by the Swedish Working Dog Association (SWDA) (55, 58).

Participation in the internet-based questionnaire was not restricted to geographic location or type of dog. Inclusion criteria were: dog born 2005 or later; participating in a sport discipline and/or working trial organized by the SWDA at any level at least once; owner access to the internet; and willingness and ability to complete an online survey in Swedish. Participation was initiated when the respondent clicked an embedded hyperlink that directly accessed the appropriate survey. The respondent could fill in the questionnaire for several additional dogs.

Questionnaire

An online survey was developed by veterinarians, veterinary physiotherapists, a statistician, and experienced obedience and working trial judges. The questionnaire was tested in a pilot group of dog handlers and adjusted accordingly prior to publishing. The final version of the questionnaire contained mainly close-ended multiple choice questions in Swedish. The results from a qualitative content analysis of narrative data from open-ended questions in the survey have been published elsewhere (59). The survey was distributed by means of an internet survey site (Google Forms, Google LLC, Mountain View, CA, USA) to facilitate data collection. The survey was initiated on February 1, 2019 and remained open for 2 months until April 3, 2019. Recruitment strategies included advertisements with the survey link at the internet sites of the SWDA (02/01/2019 and 03/25/2019) and the Swedish Kennel Club (03/27/2019), and social media groups. Survey participation, i.e., responding to an anonymous online questionnaire, was entirely voluntary.

Based on the F.I.T.T.-principle, items in the questionnaire were targeting various components of physical activity (15, 18, 19). Frequencies, two levels of intensity, time (duration) and types of physical activities and sport-specific training were reported by respondents. Duration of physical activity was divided into low-moderate and vigorous level of intensity, respectively (27, 41, 60). Low to moderate intensity was represented by one item targeting daily physical activity, e.g., walks, and vigorous intensity was targeted by physical activities resulting in hard panting, e.g., off-leach, running, swimming (26, 27, 41, 60). In addition, the questionnaire also included items about the dogs' characteristics, such as age, weight, sex, breed, health history, and management routines, e.g., surfaces used for physical activity and sport-specific training, frequency and type of warm-up activity. In questions concerning types of physical activity, surfaces used, and types of warm-up activities the respondents were given an opportunity to add information in open-field boxes. Table 1 shows the details of the topics and variables relevant for this study.

Data analysis and statistical methods

Descriptive baseline characteristics were summarized using frequencies and proportion (%) in categorical data and for continuous data distributions were manually inspected. Mean and standard deviation (SD) was calculated for normally distributed variables and median and inter quartile range (IQR) for non-normally distributed data. Variables regarding demographics, health history, physical activity, sport-specific training and management are described in Table 1.

Working trial disciplines including mondioring were further combined into four categories, i.e., messenger,

TABLE 1 Questions and variables regarding demographics, health history, physical activity, sport-specific training, and management.

Topic	Variable	Categories
Individual characteristics	Age	<1 year/1–2 years/2–4 years/4–6 years/6–8 years/8–10 years/>10 years/Deceased
	Sex	Sexually intact male/Neutered male/Sexually intact female/Spayed female
	Weight	Kilograms
	Breed group	Breed group 1–10 by Federation Cynologique International
	Breed	Breed by Federation Cynologique International or breed acknowledged by the Swedish Kennel Club/mixed breed
Health history	Hip dysplasia (Federation Cynologique International grade)	Grade A-E/do not know
	Elbow dysplasia (Federation Cynologique International grade)	No remarks/minor/moderate/severe/do not know
	Mental evaluation	Participated in official mental test/mental description/dog behavior personality description yes/no
	Injury	Never/Once/2–3 times/4 times or more
Physical activity	Time (duration) of low to moderate daily physical activity (minutes per day)	<15 min/15–30 min/30–60 min/1–2 h/2–3 h/3–4 h/>5 h
	Time (duration) of vigorous physical conditioning exercise (e.g., off-leach, running, swimming) (minutes per week)	0 min/<30 min/30–60 min/60–90 min/90–120 min/120–180 min/>180 min
	Proportion of time spent off-leash	Never/<25%/25–50%/50–75%/75–100%
	Preferred self-selected gait	Unwilling to move/Walk/Pace/Trot/Gallop/Do not know
	Physical conditioning exercise	Yes/no
	Content of physical conditioning exercise	Categories defined according to targeted component of canine fitness i.e., cardiorespiratory endurance, musculoskeletal components or a combination of both.
	Frequency of play sessions with other dogs (monthly)	Never/Approximately once per month/Approximately once every second week/Approximately once per week/Several times per week/Every day/Several times per day
	Surface used for physical activity	Natural grass/Turf/Forest/Field/Gravel/Sand/Asphalt/Stone/Concrete/Snow/Ice/Indoor venue/Home flooring/Other—water/Other—mobile/Other—soft. (see Supplementary Table 2).
Sport-specific training	Time (duration)—hours per week in categories and mean per category	0–1 h/1–2 h/2–3 h/3–5 h/5–7 h/7–10 h/>10 h
	Frequency of sport-specific training over a month	Never/Once a month/Every other week/Once per week/Several times per week/Daily/Several times per day
	Frequency of selected types of activities over the year	Never/Once a month/Every other week/Once per week/Several times per week/Daily/Several times per day. Reported as frequencies and total number of physical activities. Selected activities: tracking, search, mushing, obedience, messenger, International Utility Dog trial phase c - protection, Swedish schutzhund, mondioring, protection related to Police K9 or guard dog duty, hunting, game tracking, search and rescue, freestyle, patrol, racing, herding, agility, nose work, rally obedience, drag weight/weight pull.
	Participation in dog sports and working trials	Participation in agility, obedience, rally, any working dog discipline, messenger, protection, search, tracking, and number of disciplines
	Sport specialization - sport training and competition in one Swedish Working Dog Association discipline for ≥10 months per year.	Presented as a proportion by sport discipline and by the whole cohort.
		Specializing in agility, obedience, rally obedience, working trial discipline (i.e., messenger, protection, search, tracking).

(Continued)

TABLE 1 (Continued)

Topic	Variable	Categories
	Surface used for sport-specific training	Natural grass/Turf/Forest/Field/Gravel/Sand/Asphalt/Stone/Concrete/Snow/Ice/Indoor venue/Home flooring/Other—water/Other—mobile/Other—soft. (see Supplementary Table 2).
Total work load	Time (duration) in low to moderate daily physical activity, vigorous physical conditioning exercise and sport-specific training (hours per week in categories and mean per category)	Median (inter quartile range)
Warm-up	Frequency of participation	Never/Seldom/Sometimes/Often/Always
	Time (duration) (minutes per session)	0 min/1–10 min/11–20 min/21–30 min/31 min or more
	Content of warm-up activities	Categories defined according to targeted effect general/sport specific/mobility/passive/other

protection, search, tracking. These are defined in detail in Supplementary Table 1. We further calculated the total number of disciplines a dog participated in.

Sport specialization was defined as competing in only one discipline and training that sport for ≥ 10 months per year. This is analogous with sport specialization in human adolescents (23, 61).

Total work load per week was calculated as assigning the middle of time point in the interval for duration of daily physical activity, duration of vigorous physical conditioning exercise, and duration of sport-specific training, per week. Thus, an interval of 0–1 h yielded a training time of 30 min, 1–2 h was set to 90 min, and so on, except for the daily physical activity category of <15 min per day, which was assigned 0 min. The mean total work hours per week was calculated as [(duration of daily physical activity per day × 7) + duration of vigorous physical conditioning exercise + duration of sport-specific training per week]/60.

Physical conditioning exercise to improve or maintain canine fitness, was categorized as "cardiorespiratory", "musculoskeletal", or a "combination" of both (4, 13, 15, 19, 20). Cardiorespiratory activities included aerobic and/or anaerobic endurance, e.g., intervals in gallop, galloping in sand, trot or gallop off-leash with handler riding bike. Musculoskeletal activities included muscular endurance, strength, power, stability, balance, mobility or agility, such as parkour, drag weight, weight vest during walking, jumping technique exercises, balance training exercises, tricks, static stretching, walking in snow and on uneven surfaces, underwater treadmill training, or cavaletti. Activities requiring both cardiorespiratory and musculoskeletal components of physical fitness, e.g., hill climbing, running, agility, swimming, canicross, bikejioring, off-leash exercise in the forest, treadmill, were categorized as a "combination".

Warm-up activities were categorized as "general", "sport specific", "mobility", "passive" and "other" analogous with components previously described in human and canine literature (15, 22, 24, 62, 63). General warm-up activities aiming at increasing body temperature included locomotion in walk and/or trot. Sport-specific warm-up activities included movements and tasks that were to be performed in the upcoming discipline, e.g., heelwork, jumping, bite work, off-leash search for objects, intervals in gallop. Mobility warm-up activities included dynamic and/or static stretching with a purpose to increase flexibility, e.g., play, tricks, walking in circles or with increased active joint range of motion, locomotion off-leash, short intervals in canter. Passive warm-up included massage and/or warm blanket, and "Other" warm-up included unspecified physical warm-up and/or mental preparation.

Main surfaces used for physical activity, physical conditioning exercise and sport-specific training were categorized into 15 different categories, specified in Supplementary Table 2.

Sensitivity analyses were performed to assess the possible influence of recall bias on inconsistencies in reported frequency of sport-specific training over the year. In the first sensitivity analysis we excluded all dogs that did not participate in sport-specific training during the past year. A second sensitivity analysis was performed in which all deceased dogs were excluded.

Ethical consideration

This research was conducted as online reported data from handlers of sporting and working trial dogs, without subjecting the dogs to any kind of stress or suffering. The respondents were informed and free to choose whether to participate in the study. All respondents were debriefed in writing about the content and purpose of the study. In the first paragraph of the online questionnaire it was stated that by completing and submitting the online questionnaire the respondents were providing their informed consent. No personal or sensitive data were collected from the respondents and all data on sporting and working dogs were anonymous. Respondents could possibly withdraw their responses only by contacting the responsible researcher (A.E.) with descriptive data about their dog. Otherwise, the responses could not be traced back to detect individual responses.

Results

Cohort characteristics

A total of 1615 survey answers were received. Out of these, 29 were excluded due to incomplete responses on sport participation. Four dogs were further excluded due to inconsistencies between reported participation in dog training activities and reported training time, resulting in 1582 unique dogs included in the analysis. Full characteristics are presented in Table 2. The age category 4–6 years was the most common ($n = 428$, 27.1%). Of all dogs, $n = 692$ (44%) were intact females, $n = 205$ (13%) spayed females, $n = 518$ (33%) intact males and $n = 167$ (11%) neutered males. The median weight was 23 kg (IQR 14 kg, n missing = 6). Most dogs were from FCI group 1 (Sheepdogs and Cattle dogs) ($n = 895$, 57%), while group 8 (Retrievers, Flushing dogs, Water dogs) and group 2 (Pinscher and Schnauzer—Molossoid and Swiss Mountain and Cattle dogs) were second and third most common ($n = 232$ (15%) and $n = 200$ (13%), respectively). The distribution across the FCI breed groups can be seen in Table 2. The five most common breeds were German Shepherd Dog ($n = 205$, 13%), Border Collie ($n = 133$, 8%), Belgian Shepherd, Malinois ($n = 111$, 7%), Australian Shepherd ($n = 86$, 5%) and Australian Kelpie ($n = 76$, 5%). See Supplementary Table 3 for the distribution across all breeds. Only a small proportion of the dogs did not have an FCI evaluation for hip dysplasia ($n = 256$, 16%) or elbow dysplasia ($n = 418$, 26%), but $n = 189$ (12%) of the dogs were reported to have hip dysplasia and $n = 65$ (4%) elbow dysplasia (Table 2). Moreover, $n = 1229$ (78%) had participated in any of the official mental evaluations available in Sweden and $n = 844$ (53%) had participated in structural conformation evaluation performed by an official judge, e.g., at open dog show.

The year prior to the study, $n = 1329$ (84%) of the dogs, had been trained for competition. Over half of the dogs ($n = 919$, 58%) had ever suffered from an injury. The proportion of injured dogs varied slightly across the disciplines with the highest proportion in agility dogs ($n = 276$, 64%) and the lowest in obedience ($n = 441$, 56%).

Physical activity patterns

Almost one third of the dogs ($n = 453$, 29%) received <1 h per day of physical activity, e.g., walks, and only 3% ($n = 51$) were never exercised off leash. Trot was reported as the primary self-selected gait in 57% ($n = 907$) of the dogs and gallop in 32% ($n = 499$). A fifth ($n = 319$, 20%) of the dogs never played with other dogs. The majority of the dogs ($n = 1328$, 84%) had more than 1 h of vigorous physical exercise per week (Table 3).

Almost three quarters of the participants ($n = 1119$, 71%) added physical conditioning exercise to improve and/or maintain their dogs' physical capacity in sports. Nearly half of the participants ($n = 732$, 46%) were addressing musculoskeletal components of physical capacity through physical conditioning activities (Tables 4, 5).

With regards to sport-specific training, 60% ($n = 953$) received at least 3 h of training per week and only a very small portion ($n = 35$, 2%) trained their specific discipline less than once per week (Tables 4, 5).

There was variability in the number of disciplines participated in through the whole cohort, with a range from one to five. Most commonly reported was one discipline ($n = 767$, 48%) and two disciplines ($n = 541$, 34%). Three dogs (2%) were competing in five disciplines, 50 dogs (3%) in four disciplines and 221 dogs (14%) in three disciplines. Of the dogs practicing only one discipline, 38% ($n = 294$) were considered specialized since they were actively training that discipline for ≥10 months per year. Among the agility dogs, 20% ($n = 84$) were specialized, while for the other disciplines, the proportions of specialized dogs were around 10%.

Minimum and maximum total work load per week, i.e., daily physical activity, vigorous physical conditioning exercise and sport-specific training combined, were 0.5 and 49 h per week, respectively. Median total work load was 16.5 h (IQR 9.0) per week in the full cohort and in general there was a higher total work load for dogs in the working trial disciplines (Tables 4, 5).

In addition to various sporting and working trial disciplines there were also interactions with other physically demanding activities. Dogs from all disciplines participated to some extent in canicross (Figure 1). Regardless of primary discipline, almost all dogs also participated in obedience, with the exception of agility where only 70% of the agility dogs participated. For tracking, 35% of the agility dogs, 56% of the rally obedience dogs, and 79% of the obedience dogs participated. In contrast, dogs competing in agility, obedience and rally obedience never participated in protection, search, rescue or patrol activities (Figure 1). Participation and gradient proportions of interaction in various disciplines and other physically demanding activities over the year are illustrated in Figure 1. Frequency of selected types of activities (i.e., tracking, search, mushing, obedience, messenger, utility dog protection, Swedish schutzhund, mondioring, protection related to police K9 or guard dog duty, hunting, game tracking, search and rescue, freestyle, patrol, racing, herding, agility, nose work, rally obedience, drag weight/weight pull), over the year is further defined in Table 1.

TABLE 2 Demographics and characteristics of sporting and working trial dogs ($n = 1582$).

	Full cohort	Agility	Obedience	Rally obedience	Working*
N dogs	1582	430	790	596	847
Age					
<1 year	2 (0.1)	0 (0)	1 (0.1)	1 (0.2)	0 (0)
1–2 years	91 (5.8)	12 (2.8)	48 (6.1)	35 (5.9)	26 (3.1)
2–4 years	387 (24.5)	99 (23)	190 (24.1)	117 (19.6)	200 (23.6)
4–6 years	428 (27.1)	122 (28.4)	204 (25.8)	173 (29)	216 (25.5)
6–8 years	268 (16.9)	77 (17.9)	136 (17.2)	104 (17.4)	153 (18.1)
8–10 years	207 (13.1)	62 (14.4)	110 (13.9)	95 (15.9)	120 (14.2)
>10 years	94 (5.9)	43 (10)	50 (6.3)	45 (7.6)	51 (6)
Deceased	105 (6.6)	15 (3.5)	51 (6.5)	26 (4.4)	81 (9.6)
Gender					
Sexually intact male	518 (32.7)	119 (27.7)	257 (32.5)	174 (29.2)	307 (36.2)
Neutered male	167 (10.6)	59 (13.7)	81 (10.3)	68 (11.4)	69 (8.1)
Sexually intact female	692 (43.7)	180 (41.9)	359 (45.4)	267 (44.8)	361 (42.6)
Spayed female	205 (13)	72 (16.7)	93 (11.8)	87 (14.6)	110 (13)
Median weight (kgs) (IQR)	23 (14)	14 (10.7)	24 (12)	20 (13)	28 (11)
FCI Breed group					
1 Sheepdogs and Cattledogs	895 (56.6)	237 (55.1)	460 (58.2)	266 (44.6)	564 (66.6)
2 Pinscher and Schnauzer	200 (12.6)	19 (4.4)	102 (12.9)	47 (7.9)	152 (17.9)
3 Terriers	59 (3.7)	29 (6.7)	27 (3.4)	34 (5.7)	14 (1.7)
4 Dachshunds	2 (0.1)	2 (0.5)	0 (0)	0 (0)	0 (0)
5 Spitz and primitive types	44 (2.8)	21 (4.9)	12 (1.5)	32 (5.4)	7 (0.8)
6 Scent hounds and related breeds	7 (0.4)	1 (0.2)	3 (0.4)	6 (1)	1 (0.1)
7 Pointing Dogs	16 (1)	3 (0.7)	8 (1)	12 (2)	3 (0.4)
8 Retrievers/Flushing and Water Dogs	232 (14.7)	39 (9.1)	137 (17.3)	123 (20.6)	94 (11.1)
9 Companion and Toy Dogs	72 (4.6)	49 (11.4)	26 (3.3)	41 (6.9)	10 (1.2)
10 Sighthounds	9 (0.6)	3 (0.7)	1 (0.1)	9 (1.5)	1 (0.1)
Mixed breed	46 (2.9)	27 (6.3)	14 (1.8)	26 (4.4)	1 (0.1)
Hip dysplasia (FCI grade)					
A	776 (49.1)	164 (38.1)	434 (54.9)	269 (45.1)	498 (58.8)
B	362 (22.9)	88 (20.5)	178 (22.5)	124 (20.8)	211 (24.9)
C	157 (9.9)	36 (8.4)	83 (10.5)	62 (10.4)	86 (10.2)
D	30 (1.9)	8 (1.9)	15 (1.9)	10 (1.7)	17 (2)
E	2 (0.1)	0 (0)	1 (0.1)	0 (0)	2 (0.2)
Unknown	255 (16.1)	134 (31.2)	79 (10)	131 (22)	33 (3.9)
Elbow dysplasia (FCI grade)					
Normal	1099 (69.5)	214 (49.8)	596 (75.4)	378 (63.4)	704 (83.1)
Mild	51 (3.2)	5 (1.2)	30 (3.8)	18 (3)	35 (4.1)
Moderate	8 (0.5)	1 (0.2)	6 (0.8)	4 (0.7)	5 (0.6)
Severe	6 (0.4)	0 (0)	4 (0.5)	1 (0.2)	5 (0.6)
Unknown	418 (26.4)	210 (48.8)	154 (19.5)	195 (32.7)	98 (11.6)
Official mental evaluation	1229 (77.7)	217 (50.5)	673 (85.2)	423 (71)	842 (99.4)
Official conformational evaluation	844 (53.4)	212 (49.3)	432 (54.7)	376 (63.1)	476 (56.2)

Data are presented in frequencies and proportions (%).
*Working trial disciplines were defined as Swedish Schutzhund, tracking (SWDA), search (SWDA), messenger (SWDA), patrol (SWDA), International Utility Dog trials (tracking, obedience, protection, search and rescue), International Nordic Style, BH/VT, and mondioring. SWDA, Swedish Working Dog Association.

TABLE 3 Physical activity including physical conditioning exercise reported in the full cohort of competition dogs ($n = 1582$) and stratified by participation in various disciplines.

	Full cohort	Agility	Obedience	Rally obedience	Working*
N dogs	1582	430	790	596	847
Daily physical activity (e.g., walks)					
<15 min	12 (0.8)	2 (0.5)	4 (0.5)	2 (0.3)	9 (1.1)
15–30 min	82 (5.2)	19 (4.4)	41 (5.2)	25 (4.2)	48 (5.7)
30–60 min	359 (22.7)	98 (22.8)	182 (23.0)	138 (23.2)	201 (23.7)
1–2 h	724 (45.8)	203 (47.2)	357 (45.2)	272 (45.6)	386 (45.6)
2–3 h	321 (20.3)	86 (20.0)	158 (20.0)	129 (21.6)	158 (18.7)
3–4 h	64 (4.0)	16 (3.7)	40 (5.1)	23 (3.9)	35 (4.1)
>5 h	20 (1.3)	6 (1.4)	8 (1.0)	7 (1.2)	10 (1.2)
Duration (time) of vigorous physical conditioning exercise (e.g., off-leash, running, swimming) per week					
0 min	8 (0.5)	3 (0.7)	5 (0.6)	3 (0.5)	4 (0.5)
<30 min	76 (4.8)	23 (5.3)	41 (5.2)	49 (8.2)	28 (3.3)
30–60 min	170 (10.7)	43 (10.0)	92 (11.6)	79 (13.3)	93 (11.0)
1–1.5 h	240 (15.2)	78 (18.1)	114 (14.4)	99 (16.6)	121 (14.3)
1.5–2 h	244 (15.4)	68 (15.8)	120 (15.2)	81 (13.6)	126 (14.9)
2–3 h	292 (18.5)	79 (18.4)	146 (18.5)	105 (17.6)	158 (18.7)
>3 h	552 (34.9)	136 (31.6)	272 (34.4)	180 (30.2)	317 (37.4)
Percentage of physical activity spent off leash					
Never	51 (3.2)	18 (4.2)	22 (2.8)	28 (4.7)	21 (2.5)
<25%	257 (16.2)	86 (20.0)	126 (15.9)	116 (19.5)	111 (13.1)
25–50%	265 (16.8)	82 (19.1)	131 (16.6)	119 (20.0)	133 (15.7)
50–75%	369 (23.3)	100 (23.3)	203 (25.7)	128 (21.5)	199 (23.5)
75–100%	640 (40.5)	144 (33.5)	308 (39.0)	205 (34.4)	383 (45.2)
Frequency of play sessions with other dogs					
Never	319 (20.2)	56 (13.0)	159 (20.1)	85 (14.3)	225 (26.6)
Monthly	191 (12.1)	43 (10.0)	110 (13.9)	73 (12.2)	105 (12.4)
Every other week	97 (6.1)	28 (6.5)	51 (6.5)	40 (6.7)	50 (5.9)
Weekly	131 (8.3)	39 (9.1)	74 (9.4)	60 (10.1)	67 (7.9)
Several times per week	200 (12.6)	58 (13.5)	98 (12.4)	91 (15.3)	96 (11.3)
Daily	392 (24.8)	129 (30.0)	197 (24.9)	153 (25.7)	188 (22.2)
Several times per day	252 (15.9)	77 (17.9)	101 (12.8)	94 (15.8)	116 (13.7)
Preferred self-selected gait					
Unwilling to move	1 (0.1)	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)
Walk	41 (2.6)	14 (3.3)	20 (2.5)	23 (3.9)	17 (2.0)
Pace	120 (7.6)	38 (8.8)	74 (9.4)	50 (8.4)	73 (8.6)
Trot	907 (57.3)	249 (57.9)	443 (56.1)	359 (60.2)	478 (56.4)
Gallop	499 (31.5)	121 (28.1)	248 (31.4)	158 (26.5)	274 (32.3)
I don't know	14 (0.9)	8 (1.9)	5 (0.6)	5 (0.8)	5 (0.6)

Data are presented in frequencies and proportions (%).
*Working disciplines were defined as Swedish Schutzhund, tracking (SWDA), search (SWDA), messenger (SWDA), patrol (SWDA), International Utility Dog trials (tracking, obedience, protection, search and rescue), International Nordic Style, BH/VT, and mondioring. SWDA, Swedish Working Dog Association.

Sporting and working dog management

Three quarters of the dogs ($n = 1202$, 76%) participated in warm-up exercises prior to competition and training. Nearly half of the dogs ($n = 781$, 49%) had warm-up sessions lasting 1–10 min. The most common component of physical warm-up was general exercises ($n = 1400$, 89%), and in additionally 45% ($n = 711$) mobility warm-up exercises was

TABLE 4 Sport-specific training and physical conditioning exercise in the full cohort of competition dogs ($n = 1582$) and stratified by participation in various disciplines.

	Full cohort	Agility	Obedience	Rally obedience	Working*
N dogs	1582	430	790	596	847
Duration of sport-specific training per week					
0–1 h	103 (6.5)	46 (10.7)	42 (5.3)	39 (6.5)	35 (4.1)
1–2 h	238 (15.0)	85 (19.8)	102 (12.9)	100 (16.8)	101 (11.9)
2–3 h	288 (18.2)	92 (21.4)	142 (18.0)	135 (22.7)	146 (17.2)
3–5 h	398 (25.2)	116 (27.0)	208 (26.3)	150 (25.2)	202 (23.8)
5–7 h	303 (19.2)	56 (13.0)	166 (21.0)	105 (17.6)	179 (21.1)
7–10 h	153 (9.7)	21 (4.9)	77 (9.7)	46 (7.7)	107 (12.6)
More than 10 h	99 (6.3)	14 (3.3)	53 (6.7)	21 (3.5)	77 (9.1)
Frequency of sport-specific training in total					
Never	1 (0.1)	0 (0.0)	1 (0.1)	0 (0.0)	1 (0.1)
Once a month	8 (0.5)	4 (0.9)	3 (0.4)	4 (0.7)	1 (0.1)
Every other week	26 (1.6)	12 (2.8)	9 (1.1)	15 (2.5)	6 (0.7)
Once per week	123 (7.8)	45 (10.5)	56 (7.1)	49 (8.2)	63 (7.4)
Several times per week	946 (59.8)	272 (63.3)	466 (59.0)	352 (59.1)	505 (59.6)
Daily	426 (26.9)	88 (20.5)	217 (27.5)	154 (25.8)	250 (29.5)
Several times per day	52 (3.3)	9 (2.1)	38 (4.8)	22 (3.7)	21 (2.5)
Total work load per week **					
Median (IQR)	16.5 (9.0)	15.5 (8.6)	17.0 (9.6)	15.8 (9.2)	16.8 (9.4)
Content of physical conditioning exercise* **					
Cardiorespiratory[1]	79 (5.0)	9 (2.1)	40 (5.1)	26 (4.4)	53 (6.3)
Muscular[2]	732 (46.3)	175 (40.7)	376 (47.6)	250 (41.9)	440 (51.9)
Combination[3]	308 (19.5)	133 (30.9)	145 (18.4)	138 (23.2)	109 (12.9)

Data are presented in frequencies and proportions (%).

*Working trial disciplines were defined as Swedish Schutzhund, tracking (SWDA), search (SWDA), messenger (SWDA), patrol (SWDA), International Utility Dog trials (tracking, obedience, protection, search and rescue), International Nordic Style, BH/VT, and mondioring. SWDA, Swedish Working Dog Association.

**Total work load per week was defined as hours per week in daily physical activity, vigorous physical conditioning exercise and sport-specific training.

***Conditioning was defined as physical exercises target to improve and/or maintain cardiorespiratory or musculoskeletal physical fitness components, or as a combination of both.

[1] Activities including aerobic and/or anaerobic endurance, e.g., intervals in gallop, galloping in sand, trot or gallop of leash with handler riding bike.

[2] Activities requiring muscular endurance, strength, power, stability, balance, mobility or agility, such as parkour, drag weight, weight vest during walking, jumping technique exercises, balance training exercises, tricks, static stretching, walking in snow and on uneven surfaces, under water treadmill training, cavaletti.

[3] Activities requiring both cardiorespiratory and musculoskeletal components of physical fitness, e.g., hill climbing, running, agility, swimming, canicross, bikejioring, off-leash exercise in the forest, treadmill.

performed, and 18% (n = 288) were targeting sport-specific activities. Passive methods prior to training and competition, i.e., massage and/or warm blankets, were used in 4% (n = 57), and other un-specified warm-up techniques and/or mental preparation were reported in 5% (n = 74) of the dogs (Table 6). Data regarding frequency, duration and content of warm-up stratified by working disciplines are presented in Table 7.

Main surfaces used for physical activity were natural grass (n = 1434, 90%), gravel (n = 1209, 76%), snow (n = 1147, 72%), forest (n = 1481, 934%), and asphalt (n = 808, 51%). For sport-specific training the most commonly used surfaces were natural grass (n = 1578, 99.5%), gravel (n = 1141, 72%), snow (n = 1126, 71%), forest (n = 1218, 77%), asphalt (n = 638, 40%), turf (n = 897, 57%), and indoor venue floorings (n = 581, 37%) (Table 8). Indoor home flooring and concrete were never used for physical activity. The categories are specified in Supplementary Table 2.

Sensitivity analysis

Excluding dogs that did not participate in sport-specific training during the past year or dogs that were deceased did not change the results.

Discussion

This study provides detailed insight into physical activity patterns and sport-specific training in sporting and working dogs participating in agility, obedience, rally obedience,

TABLE 5 Sport-specific training and physical conditioning exercise stratified by working trial disciplines.

	Messenger	Protection	Search	Tracking
N dogs	33	169	226	667
Duration of sport-specific training per week				
0–1 h	0 (0.0)	4 (2.4)	9 (4.0)	27 (4.0)
1–2 h	4 (12.1)	19 (11.2)	28 (12.4)	83 (12.4)
2–3 h	5 (15.2)	16 (9.5)	39 (17.3)	113 (16.9)
3–5 h	7 (21.2)	41 (24.3)	56 (24.8)	150 (22.5)
5–7 h	4 (12.1)	50 (29.6)	47 (20.8)	151 (22.6)
7–10 h	11 (33.3)	24 (14.2)	25 (11.1)	84 (12.6)
>10 h	2 (6.1)	15 (8.9)	22 (9.7)	59 (8.8)
Frequency of sport-specific training				
Never	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)
Once a month	0 (0.0)	0 (0.0)	1 (0.4)	1 (0.1)
Every other week	0 (0.0.)	0 (0.0)	1 (0.4)	6 (0.9)
Once per week	3 (9.1)	8 (4.7)	17 (7.5)	49 (7.3)
Several times per week	17 (51.5)	102 (60.4)	142 (62.8)	400 (60.0)
Daily	13 (39.4)	57 (33.7)	58 (25.7)	193 (28.9)
Several times per day	0 (0.0)	2 (1.2)	7 (3.1)	17 (2.5)
Total work load per week*				
Median (IQR)	20.8 (9.8)	17.0 (7.2)	17.5 (10.0)	17.0 (9.5)
Content of physical conditioning exercise**				
Cardiorespiratory[1]	5 (15.2)	12 (7.1)	13 (5.8)	42 (6.3)
Muscular[2]	21 (63.6)	102 (60.4)	123 (54.4)	339 (50.8)
Combination[3]	3 (9.1)	19 (11.2)	24 (10.6)	84 (12.6)

Data are presented in frequencies and proportions (%).

*Total work load per week was defined as hours per week in daily physical activity, vigorous exercise and sport-specific training.

**Conditioning was defined as physical conditioning exercises target to improve and/or maintain cardiorespiratory or musculoskeletal physical fitness components, or as a combination of both.

[1] Activities including aerobic and/or anaerobic endurance, e.g., intervals in gallop, galloping in sand, trot or gallop of leash with handler riding bike.

[2] Activities requiring muscular endurance, strength, power, stability, balance, mobility or agility, such as parkour, drag weight, weight vest during walking, jumping technique exercises, balance training exercises, tricks, static stretching, walking in snow and on uneven surfaces, under water treadmill training, cavaletti.

[3] Activities requiring both cardiorespiratory and musculoskeletal components of physical fitness, e.g., hill climbing, running, agility, swimming, canicross, bikejioring, off-leash exercise in the forest, treadmill.

and working trial disciplines. Important demographic and descriptive data on physical activity and sport-specific patterns are presented together with information on management routines utilized by dog handlers. To our knowledge, no other studies have been conducted on these topics in dogs competing in obedience, rally obedience, and working trial disciplines.

The competition dogs in our cohort were typically 2–6 years of age and out of FCI breed groups 1, 2, and 8. In contrast to recent studies on flyball and agility dogs, where only 28 and 22% of the dogs were sexually intact (37, 40), 77% of the competing dogs in our study were unaltered. One obvious explanation is cultural differences between countries, but there may also be practical and economical explanations influencing decisions whether or not to neuter or spay a competition dog. In Sweden, neutering for reasons other than medical was prohibited by law until 1988. From a breeding perspective there are several arguments against neutering and spaying dogs. For example, the genetic diversity narrows with fewer dogs in the gene pool and potentially important individuals are lost to the gene pool if neutered (64). There are also differences in regulations for participation in sports between countries, making it more or less viable to keep a female dog intact. In Sweden, intact female dogs in heat may participate in various sporting and working disciplines such as agility, bikejoring, canicross, freestyle, international utility dog disciplines, heelwork to music, herding, mondioring, rally obedience, and obedience. In other disciplines, like the SWDA disciplines, bitches in season are not allowed to compete, but the entry fee is refunded if the dog is in heat. SWDA trials were adopted as a tool to evaluate breeding characteristics, e.g., physical and mental capacities, and workability, in working breeds, and incentives to keep females intact were thus needed. National regulations in other countries may, and do, differ with possible effects on the composition of the competing dog population.

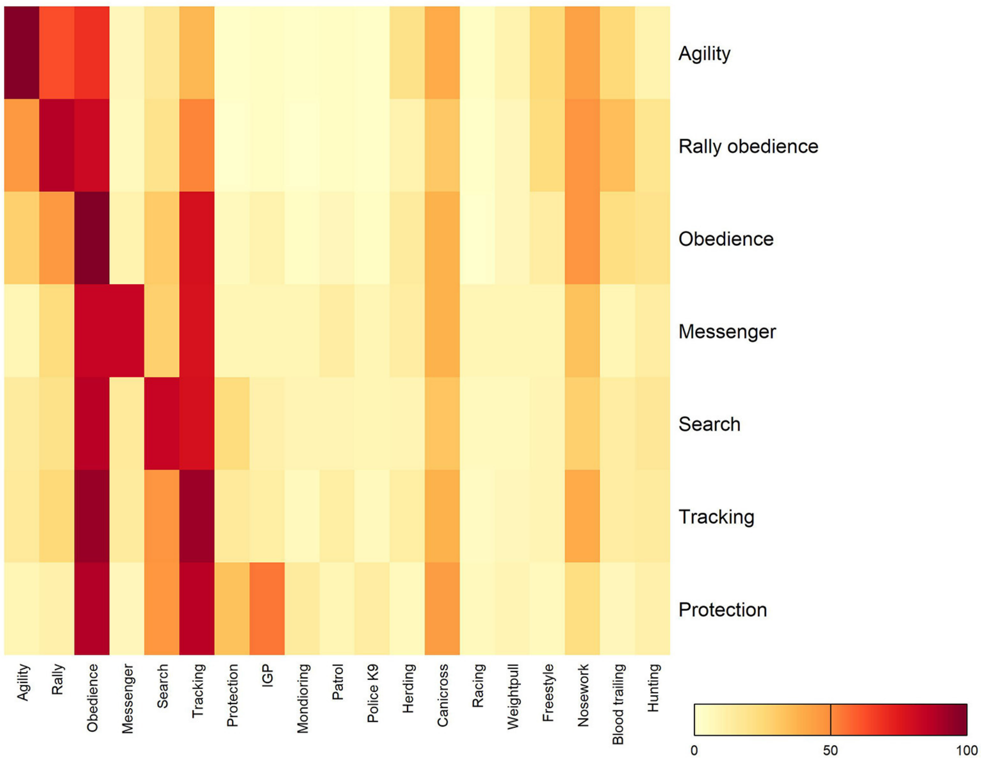

FIGURE 1
Heat map of participations and interaction in various sporting and working trial disciplines 662 (y-axis) and other physically demanding activities (x-axis) over a year in Swedish sporting 663 and working trial dogs. Gradient proportions of frequency are displayed as colors ranging from yellow (low) to red (high) are shown in the key. IGP, Internationale Gebrauchshunde Prüfungsordnung.

As many as 77% of the dogs had an official mental evaluation through participation in behavior and personality tests. The large proportion can be explained by the mandatory requirement for passing a test prior to competing in the Swedish national working trial disciplines. There seems to be a growing interest from Swedish breeders and dog owners in obtaining behavior and personality assessment in their dogs (65). Altogether, undergoing behavior and personality assessments, structural and conformational evaluations, and hip and elbow dysplasia screenings indicate that handlers of sporting and working trial dogs are compliant to breed-specific health screening programs initiated by breed clubs and the Swedish Kennel Club.

Previous studies on physical activity have shown that agility dogs in USA were walked for $\leq$2 h per week (39) while agility dogs in Finland were walked for 1.5 h per day (34). Our study confirms the longer duration of walks in Nordic agility dogs compared to American. We further extend these studies by reporting physical activity patterns of several additional disciplines. With regards to previously reported time-based levels of activity, sporting and working trial dogs in our sample exhibited moderate to high durations and moderate to vigorous intensities of physical activity (31). However, the level of intensity of the physical activity is difficult to study using self-reported data. To target intensity we designed questions addressing normal gaits of the dogs in order to capture low to moderate and vigorous levels of physical activity, as previously suggested (26, 27). To further separate vigorous intensity from low to moderate, the respondents were provided with a description of vigorous intensity as physical activity resulting in hard panting. This description is in line with a perceived exertion scale for dogs (60). For agility dogs, it has been reported that 49% were walked mostly, or always, on leash (34). One explanation for this could be to prevent the dogs from galloping and implement variability to the time spent in physical activity. Another explanation for using leash could be laws in some countries that require dogs to stay on a leash while in public. There may also be a lack of readily available free areas to be off leash and a need to protect dogs from road traffic accidents. In our study, we found a higher proportion of dogs spending more than half of their time off leash, and almost all dogs preferred the faster gaits, trot or gallop, as self-selected gaits.

We further observe that more than half of the dogs received vigorous physical conditioning exercise for more than 2 h per week and a slightly higher proportion had weekly regular play sessions with other dogs. In general, we did not notice any

TABLE 6 Frequency, duration and content of warm-up activity prior to competition and training in the full cohort of competition dogs ($n = 1582$) and stratified by participation in various disciplines.

	Full cohort	Agility	Obedience	Rally obedience	Working*
N dogs	1582	430	790	596	847
Frequency of warm-up before training or competition					
Never	21 (1.3)	1 (0.2)	8 (1.0)	8 (1.3)	10 (1.2)
Seldom	93 (5.9)	5 (1.2)	50 (6.3)	46 (7.7)	52 (6.1)
Sometimes	266 (16.8)	42 (9.8)	154 (19.5)	116 (19.5)	158 (18.7)
Often	497 (31.4)	108 (25.1)	263 (33.3)	198 (33.2)	280 (33.1)
Always	705 (44.6)	274 (63.7)	315 (39.9)	228 (38.3)	347 (41.0)
Duration of warm-up session					
0 min	25 (1.6)	2 (0.5)	12 (1.5)	9 (1.5)	10 (1.2)
1–10 min	781 (49.4)	152 (35.3)	408 (51.6)	302 (50.7)	449 (53.0)
11–20 min	640 (40.5)	223 (51.9)	309 (39.1)	239 (40.1)	323 (38.1)
21–30 min	110 (7.0)	44 (10.2)	45 (5.7)	32 (5.4)	53 (6.3)
31 min or more	26 (1.6)	9 (2.1)	16 (2.0)	14 (2.3)	12 (1.4)
Content of warm-up					
General[1]	1400 (88.5)	403 (93.7)	699 (88.5)	519 (87.1)	757 (89.4)
Sport-specific[2]	288 (18.2)	104 (24.2)	139 (17.6)	113 (19)	120 (14.2)
Mobility exercises[3]	711 (44.9)	254 (59.1)	343 (43.4)	290 (48.7)	343 (40.5)
Passive[4]	57 (3.6)	8 (1.9)	34 (4.3)	25 (4.2)	37 (4.4)
Other[5]	74 (4.7)	16 (3.7)	45 (5.7)	37 (6.2)	39 (4.6)

Data are presented in frequencies and proportions (%).

*Working trial disciplines were defined as Swedish Schutzhund, tracking (SWDA), search (SWDA), messenger (SWDA), patrol (SWDA), International Utility Dog trials (tracking, obedience, protection, search and rescue), International Nordic Style, BH/VT, and mondioring. SWDA, Swedish Working Dog Association.

[1]Increasing body temperature, e.g., by locomotion in walk and/or trot.

[2]Movements and tasks that were to be performed in the upcoming discipline, e.g., heelwork, jumping, bite work, off-leash search for objects, intervals in gallop.

[3]Dynamic and/or static stretching in purpose to increase flexibility, e.g., play, tricks, walking in circles or with increased active joint range of motion, locomotion off-leash, short intervals in canter.

[4]Massage and/or warm blanket.

[5]Unknown physical warm-up and/or mental preparation.

differences across disciplines with regards to duration and intensity in physical activity patterns. Adding sport-specific training, we observed a higher total work load in hours per week for dogs participating in messenger trials. We note that this is in line with previous findings that large high drive dogs generate more physical activity with their owners (66). One possible explanation to the moderate to high levels of activity with regards to duration of physical activity, could be the law Outdoor Access Right that gives people the right to freely roam the natural property in Sweden. Hence, the opportunity to walk, cycle, ride, ski, and camp on any land, with the exception of private gardens, near a dwelling house or land under cultivation. Another potential explanation for the moderate to high levels of activity in our sample is that the Swedish Animal Welfare Law (67) regulates the management of pet and competition dogs. For example, dogs are not allowed to be held in crates or on leash indoors, and dog owners have to walk their dogs at least every 6 h during the day.

Sport-specific training was typically conducted several times per week or daily, and lasted for at least 3 h every week in 60% of the dogs in the full cohort. Previous studies have presented conflicting information regarding the duration of weekly training in agility dogs (34, 52). Our findings show that in agility, nearly half of the dogs trained for 3 h or more per week, which is a marked increase of sport-specific training when compared to Finnish and American dog populations where the dogs were reported to train 18 min and <2 h per week, respectively (34, 39). There is increased access to indoor training facilities in Sweden lately, which has increased the availability of agility training over all four seasons, and it should be noted that compared to other disciplines, the total work load for the Swedish agility dogs did not differ. Our study further expands the knowledge on physical activity and sport-specific patterns also in obedience, rally obedience, and working trial dogs, which have not been reported previously. We observe that almost all dogs, regardless of major sport discipline, participated in obedience and tracking activities. In comparison, only 24% of Finnish competitive agility dogs participated in additional physically demanding activities (34). Possible explanations for the differences between the studies could be

TABLE 7 Frequency, duration and content of warm-up stratified by working trial disciplines.

	Messenger	Protection	Search	Tracking
N dogs	33	169	226	667
Frequency of warm-up before training or competition				
Never	0 (0.0)	5 (3.0)	1 (0.4)	5 (0.7)
Seldom	2 (6.1)	6 (3.6)	11 (4.9)	41 (6.1)
Sometimes	5 (15.2)	22 (13.0)	44 (19.5)	123 (18.4)
Often	10 (30.3)	52 (30.8)	82 (36.3)	222 (33.3)
Always	16 (48.5)	84 (49.7)	88 (38.9)	276 (41.4)
Duration of warm-up session				
0 min	0 (0.0)	5 (3.0)	1 (0.4)	5 (0.7)
1–10 min	18 (54.5)	96 (56.8)	120 (53.1)	348 (52.2)
11–20 min	12 (36.4)	58 (34.3)	93 (41.2)	264 (39.6)
21–30 min	2 (6.1)	10 (5.9)	10 (4.4)	40 (6.0)
31 min or more	1 (3.0)	0 (0.0)	2 (0.9)	10 (1.5)
Content of warm-up				
General[1]	31 (93.9)	142 (84)	204 (90.3)	612 (91.8)
Sport-specific[2]	3 (9.1)	35 (20.7)	28 (12.4)	88 (13.2)
Mobility exercises[3]	15 (45.5)	60 (35.5)	99 (43.8)	271 (40.6)
Passive[4]	1 (3.0)	9 (5.3)	9 (4.0)	26 (3.9)
Other[5]	0 (0.0)	11 (6.5)	9 (4.0)	30 (4.5)

Data are presented in frequencies and proportions (%).
[1]Increasing body temperature, e.g., by locomotion in walk and/or trot.
[2]Movements and tasks that were to be performed in the upcoming discipline, e.g., heeling, jumping, bite work, off-leash search for objects, intervals in gallop.
[3]Dynamic and/or static stretching in purpose to increase flexibility, e.g., play, tricks, walking in circles or with increased active joint range of motion, locomotion off-leash, short intervals in canter.
[4]Massage and/or warm blanket.
[5]Unknown physical warm-up and/or mental preparation.

that our present study targeted dog owners active in SWDA, with local clubs traditionally organizing various types of competitions and thus agility handlers with an interest also in other dog sports, while the Finnish study collected data on primarily agility focused handlers with (potentially) less interest in other sports.

We further observe a higher proportion of injured dogs in our study compared to previous reports of 8–42% injured dogs (39, 50, 51, 53, 68), while we found 58% of the dogs ever being injured. Possible explanations could be differences in the definitions of injuries between the studies, whether or not injuries were confirmed by a veterinarian or not, and if the reported injuries were sports-related or if occurred in another context. More research is needed on risk and protective factors associated to injuries in sporting and working trial dogs.

Warm-up and physical conditioning exercise for the dogs were established routines among dog handlers in our study. However, cardiorespiratory conditioning alone was generally performed only occasionally or not at all. Regular warm-up, prior to training or competition, seemed to be especially well established amongst handlers of agility dogs. These results are in line with data previously reported in agility dogs, indicating that the vast majority performed warm-up activities prior to training or competition (34, 54).

Differences across disciplines regarding surface types used for physical activity and sport-specific training were observed in this study. Clearly, outdoor surfaces, e.g., natural grass, forest, gravel, snow, and asphalt, were mainly used for physical activity. Sport-specific training was also practiced outdoors, but indoor facilities, artificial turf, and other indoor venue surfaces were used as well. Field surfaces and possible relationships with sport-related injuries and performance have been extensively evaluated in human and equine science, but is still a severely unexplored topic in canine athletes.

The design of this study entails certain strengths. The survey approach made it possible to reach out to several sport disciplines covered by the main organization, the Swedish Kennel Club. The full cross-sectional data set was collected over a specific period in time and the information about the opportunity to participate in the study could reach all dog handlers with access to internet at the same time. In this way, we obtained large amount of detailed information

TABLE 8 Main surfaces used for physical activity and sport-specific training in competition dogs ($n = 1582$).

	Physical activity *N* (%)	Sport-specific training *N* (%)
Natural grass	1434 (90.4)	1578 (99.5)
Forest	1481 (93.4)	1218 (76.8)
Gravel	1209 (76.2)	1141 (71.9)
Snow	1147 (72.3)	1126 (71.0)
Artificial turf	4 (0.3)	897 (56.6)
Asphalt	808 (50.9)	638 (40.2)
Indoor venue	3 (0.2)	581 (36.6)
Home flooring	0	51 (3.2)
Other water	41 (2.6)	12 (0.8)
Other soft	2 (0.1)	33 (2.1)
Sand	25 (1.6)	10 (0.6)
Other mobile	16 (1.0)	0
Field	13 (0.8)	8 (0.5)
Concrete	0	7 (0.4)
Stone	4 (0.3)	5 (0.3)
Ice	3 (0.2)	1 (0.1)

Data are presented in frequencies and proportions (%).

about physical activity patterns, sport-specific training, sport specialization, and management of sporting and working trial dogs. We further conducted sensitivity analyses to examine the internal validity of our study. There are also limitations in our study. First, participation was anonymous and did not collect any demographic information about the dog handlers, or about their experience as dog handlers or dog trainers. Second, we did not include any variable on functional recovery following the dogs' participation in physical activity and/or sport-specific training. There is also the possibility of recall bias, i.e., a deviation between the self-reported and the true value of the measurement, a problem well known in questionnaire studies. The use of interval categories for self-reported physical activity, used in this study, is one way of achieving more accuracy in the data (41, 60). However, 30–37% of the dogs participating in the present study spent 3 h or more per week in vigorous physical conditioning exercise. In order to fully reflect the actual time spent in vigorous physical conditioning exercise in future studies, the authors recommend to further specify the higher durations into several categories. For example, add 3–4, 4–5, 5–6, and >6 h.

In conclusion, in a cohort of Swedish sport and working trial dogs, we observe physical activity at moderate to high durations at moderate to vigorous intensities. Most dogs received physical conditioning exercise, but not all dogs were warmed up before training and competition. Our study provides veterinary professionals and dog trainers with valuable insights on the physical exposures and management routines of sporting and working trial dogs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, upon reasonable request.

Ethics statement

In accordance with the national animal ethical guidelines provided by the Swedish codes of statutes: SFS 2018:1192 and SJVFS 2019:9, ethical review and approval was not required for this animal study. The participants were informed about the content and purpose of the study, that responding was entirely voluntary, and that all data was anonymous. Respondents provided informed consent for their dogs to participate when they chose to proceed and submit the electronic questionnaire. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

Author AE was employed by Djurkliniken Gefle IVC Evidensia. Authors AH and CK were self-employed at EmpowerPhysio and Veterinär Catarina Kjellerstedt, respectively.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.976000/full#supplementary-material

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Use of acoustic myography to evaluate forelimb muscle function in retriever dogs carrying different mouth weights

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Objectives: To evaluate the effect of mouth weight on gait and relative function of forelimb muscles in retriever hunting dogs as a possible explanation for biceps tendinopathy.

Methods: Ten sound retriever dogs underwent acoustic myography, measuring efficiency (E-score), spatial summation (S-score), and temporal summation (T-score) during walk and trot on a pressure-sensitive walkway while carrying a 0 lb (0 kg), 1 lb (0.45 kg), and 3.2 lb (1.45 kg) mouth weight. Gait data included total pressure index (TPI), step length, and stance time. Statistics included a mixed effects model significant at $p < 0.05$.

Results: Forelimb TPI increased with increasing weight. There was no significant change in individual muscle parameters in response to weight. Significance was found in between-muscle comparisons. For walk, T-score was significantly lower in triceps vs. brachiocephalicus with 1 lb, not with 3.2 lb., S-score was significantly lower in the biceps at 0, 1 lb, and triceps at 0 lb. when compared to brachiocephalicus, E-score was significantly lower in deltoideus vs. brachiocephalicus at trot with l and 3.2 lb. There was an overall significant effect of muscle on T-score at trot, but no individual muscle comparison was significant.

Conclusion: Forelimb load increases with mouth weight. Deltoideus had a longer contraction time in response to increasing weight at trot when compared to brachiocephalicus. The biceps muscle did not show increased work in response to increasing weight.

Clinical relevance: The underlying etiology of biceps tendinopathies in retriever dogs remains uncertain but is not due to increasing weight.

KEYWORDS

AMG, tendinopathy, biceps, hunting, myography, weight, mouth, acoustic

Introduction

Biceps tendinopathies occur in active medium to large breed dogs (1–3). Although no breed predilection has been reported, the clinical experience in a sports medicine specialty practice is that hunting retrievers are overrepresented; hunting retrievers are 25% of the clinic population but 43% of dogs treated for biceps tendinopathy. Biceps tendinopathy in hunting dogs could be due to muscle overuse secondary to increased load on the forelimbs from carrying the weight of a game bird in the mouth–(4–6). The game retrieved can include land birds (Woodcock, Ruffled Grouse and Ring-necked Pheasants) and waterfowl (Canadian Geese, Northern Pintail, and Mallards). The various game can vary in weight from 0.39 lbs (0.18 kg) up to 13 lbs (5.91 kg)[1, 2, 3, 4].

Previous work by Bockstahler et al. (4) using pressure-sensitive plate analysis showed that peak vertical force and vertical impulse were significantly increased in the forelimbs and not the pelvic limbs when the dogs carried a 0.5, 2, and 4 kg (1.1, 4.4, and 8.8 lb) mouth weight at the walk; and that step length was longer in the forelimbs without a mouth weight as compared to all weights. Gait analysis was not performed at the trot while carrying a mouth weight in the Bockstahler study, which may be important as dogs will cover ground hunting at this gait, but often will gallop or canter to and from a retrieve; and peak vertical force (PVF) is higher at the trot than the walk even though the stance time is shorter (6, 7). The biceps aids in cranial shoulder stabilization during the stance phase of motion and assists in elbow flexion during swing phase (8), the triceps muscle is an anti-gravity muscle that braces the elbow into extension during stance phase and is antagonistic to the biceps and shoulder flexor (8). The deltoideus acts to flex the shoulder joint and plays a minor role as one of the dynamic shoulder joint stabilizers (9). The brachiocephalicus shows low muscle activity during walk and trot (7, 10).

Biceps brachii muscle activity in dogs carrying mouth weights has not been previously evaluated. If the biceps brachii does undergo relative overuse while carrying mouth weights, it could contribute to biceps tendinopathy. Acoustic Myography (AMG) is a validated non-invasive way of assessing muscle function by measuring the sound produced by muscle contractions (11, 12). As muscle fibers contract, they generate vibrations which are recorded by piezoelectric crystals located on transdermal sensors (11, 13). The piezoelectric AMG sensor is thin and minimizes interference from lateral movement on the skin as it only measures sound waves in one direction (11, 13). AMG has been used in dogs in previous studies to evaluate muscle contractions (12–14). The AMG equipment records the sound and calculates three parameters: the E, S, and T-scores with a scale of 0–10. The E-score (efficiency score) reflects coordination of the muscle and muscle activity in relation to inactivity in units of seconds (14). A decrease in E-score while the muscle is working reflects more contraction time vs. relaxation indicating early muscle fatigue (11). The S-score (spatial summation score) reflects signal amplitude as measured in millivolts (mV) (11). A low amplitude during work, indicates that the work is easy, therefore the S-score will be high (13, 14). T-score (temporal summation) is the frequency of muscle fiber recruitment in Hertz (Hz). During very hard work more muscle fibers are recruited, increasing the frequency, resulting in a lower T-score (13, 14).

The objective of this study is to evaluate the effect of mouth weight on gait and function of forelimb muscles in retriever hunting dogs to evaluate them as possible contributors to biceps tendinopathy. We hypothesized that carrying a mouth weight will result in greater recruitment of the biceps brachii, long head of the triceps, and the acromial portion of the deltoideus muscle but not the brachiocephalicus muscle in retriever hunting dogs as measured by AMG, that the muscle activity would increase with increasing weight and that this change would be more pronounced at trot. Secondly, we hypothesized that by carrying mouth weights, the total pressure index (TPI) would be increased in the forelimbs and decreased in the hindlimbs at a walk and trot, and that step length, and stance time would be decreased in the forelimbs when carrying a mouth weight.

Materials and methods

Selection criteria

The inclusion criteria to participate in the study were as follows: the dog was a retriever breed, between 2 and 7 years old, between 50 and 80 lbs (22.73–36.36 kg), and free of any previous soft tissue or orthopedic injuries. Dogs were client-owned and written client consent was obtained. The dogs had to be clinically free of lameness as determined by an orthopedic examination, radiographs and gait analysis on a pressure sensitive walkway (gait4dogCIR systems Inc, Franklin, NJ, USA). The dog had to have been active in one or more of the following activities: seasonal waterfowl or upland hunting, hunt tests, field trial, hunting retrieving training, or shed dog hunt. Other sports were also acceptable as long as the dogs met the previously mentioned sport inclusion criteria. The handler also had to believe their dog would be able to work in a heel position holding a mouth weight (dummy) of 1 lb (0.45 kg) and 3.2 lb (1.45 kg) (Real Duck Training Dummy, Moscow ID, USA) at a walk and trot for the duration of the study. Of the 19 dog prospects, 11 dogs

1 https://www.ducks.org/hunting/waterfowl-id/
2 https://www.pheasantsforever.org/Habitat/Pheasant-Facts.aspx
3 https://ruffedgrousesociety.org/grouse-facts/
4 https://ruffedgrousesociety.org/woodcock-facts/

Abbreviations: AMG, Acoustic myography; DDF, Deep digital flexor tendon; EMG, Electromyography; E-score, Efficiency score; SDFT, Superficial digital flexor tendon; S-score, Summation score; TPI, Total pressure index; T-score, Temporal summation score.

passed the inclusion criteria after the dog handler interview. Three dogs were excluded because they had previous orthopedic conditions, two dogs were reported by their handlers to likely not hold the mouth weight (dummy) for the intended time and repetitions, one dog was too fearful and reactive, one dog did not meet the weight criteria, and one dog did not show for the initial appointment.

Orthopedic evaluation, radiographs, and gait analysis for inclusion into the study

Eleven dogs underwent orthopedic examination performed by a Diplomate of the American College of Veterinary Sports Medicine and Rehabilitation (JET), radiographs of the shoulders and elbows, and gait analysis. The dog's brachial and thigh circumferences were measured using a spring weighted tape measure (Gulick II Warrenville, IL, USA) performed three times per limb with the average measurement being used (15). Each patient underwent goniometry to evaluate passive range of motion of the carpus in flexion, extension, valgus and varus, the elbow in flexion and extension, shoulder abduction angle while the shoulder is in full extension, and shoulder flexion and extension, and a biceps brachii stretch (measured as the degree of elbow extension with the shoulder in flexion and maximal extension of the elbow). Rear limb goniometry was also completed for the hock, stifle, and coxofemoral joints, evaluating passive flexion and extension. Three consecutive goniometric measurements were made for each joint, with the mean value used in accordance with published guidelines (16). If no abnormalities were identified, each dog underwent routine shoulder and elbow radiographs and those with radiographic abnormalities were excluded. One of the 11 dogs did not pass the physical examination as this dog had discomfort on biceps brachii palpation and reduced right biceps brachii stretch. The remaining 10 dogs went on to the final inclusion criteria, the gait analysis.

Gait analysis, using a pressure-sensitive walkway (Gait4dogs, Franklin, NJ, USA), was used to evaluate for lameness. The pressure-sensitive walkway has been previously validated and is calibrated by the manufacturer (17, 18). The dogs were gaited by one handler (MAW). Each dog was familiarized with the environment and walkway with a 10-minute pre-measurement period to acclimate to the room followed by two slow practice walks over the walkway. The dogs were walked and trotted on the pressure-sensitive walkway multiple times in order to obtain three valid passes on the walkway at each gait. A valid pass was recorded if the dog gaited in a straight line, did not step off the pressure-sensitive walkway, and had three gait cycles recorded each pass with a consistent gait ($<$ 10% variability in velocity in a single pass). Real-time video capture of each trial enabled confirmation of straight head position and limb contact. Proprietary designated software (Gait4software® Franklin, NJ, USA) that was made by the same company as the pressure-sensitive walkway was used for acquisition and analysis of the data. A $\leq$ 6% difference in Total Pressure index (TPI) was accepted as normal between each forelimb and each rear limb during evaluation (19–21). For acceleration during each pass, less than or equal to 10% variability was accepted.

The remaining 10 dogs passed this last inclusion criteria. This time spent during gait analysis provided a sufficient warm up for the dogs before muscle measurements, with an average time of completion of 26 min.

Comparison of the gait parameters of step length and stance time was performed with and without the harness and equipment to rule out any effect of the equipment (shaved hair, AMG sensor, gel, and adhesive) on step length and stance time prior to AMG data collection.

Data collection

Acoustic myography

Prior to data collection, the dogs had previously been acclimated to the location of the pressure-sensitive walkway having completed gait analysis to exclude lameness. The dog was then fitted with a harness (Julius-K9 IDC®, Powerharness, Tampa, FL, USA). This harness allowed the AMG recording device (CURO-Diagnostics ApS, Bagsvared, Denmark) to be fixed to the harness under the harness handle. The AMG sensors (MyoDynamik sensors, Copenhagen, Denmark) were 20 mm in diameter and connected to the recording device *via* the designated cables. Two pairs of sensors were run simultaneously, each sensor was placed at the same level on every dog using anatomical landmarks on both the left and right muscle groups.

The sensor pairing was the biceps brachii and acromial deltoideus muscles, the second muscle pairing was the brachiocephalicus and triceps long head. The sensor pairing order was randomized, each dog proceeded through the gait data collection for each pairing of muscles prior to repeating the data collection with the second muscle pairing. This placement was true for all dogs except one, where the sensor order pairing was different due to error in pairing—sensor pairing was biceps brachii and the long head of the triceps; second pairing was the brachiocephalicus and the deltoideus. For all dogs, the biceps brachii sensor was placed over the palpable muscle belly above the palpable tendon of insertion and below the palpable superficial pectoral muscle at 2/3 humeral length. The deltoideus sensor was centered at the mid-belly of the acromial portion of the deltoideus. For the brachiocephalicus and long head of the triceps, the sensor placement of the brachiocephalicus was at the level of the fourth cervical vertebrae transverse process, and the long head of the triceps, placed over the most caudal muscle belly of the triceps, which can be elevated from the rest of the muscle bellies and was placed at half humeral length (Figure 1).

After the hair at the measurement location was shaved with clippers using a #40 blade, a small amount of acoustic coupling

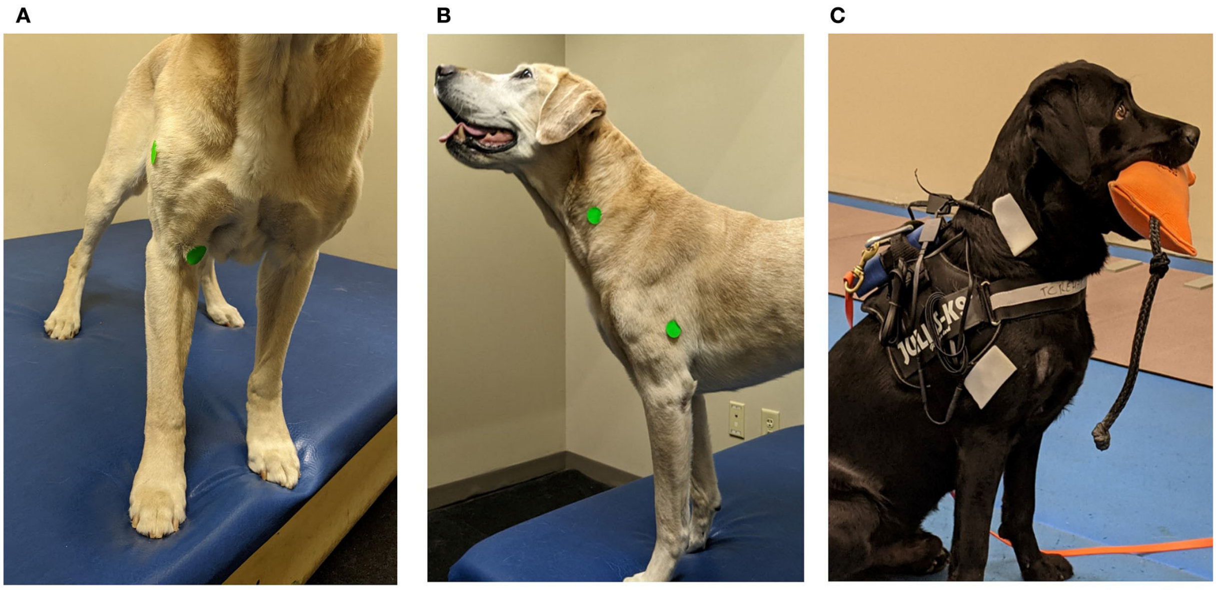

FIGURE 1
Demonstration of the acoustic myography (AMG) sensor and recording unit placement. **(A)** Green stickers used to demonstrate the placement of sensors in the research dogs. The biceps brachii placed at 2/3 of humeral length and deltoideus acromial portion is placed mid-muscle belly. The dog is a demo dog and not used in the study. **(B)** Green stickers used to demonstrate the placement of sensors in the research dogs. The brachiocephalicus sensor placed at the 4th cervical vertebrae and the triceps long head sensor placed at ½ the length of the humerus. The dog is a demo dog and not used in the study. **(C)** AMG sensor placement with large stickers placed over the small sensors on a research subject. Picture demonstrating equipment set up with sensors placed over the triceps long head and the brachiocephalicus.

gel (Ekkomarine Medico A/S, Holstebro, Denmark) was placed on the skin and on the sensor. The sensor was placed over the appropriate site and adhered using an adhesive bandage (Snøgg AS, Kristiansand, Norway) placed over the skin and the surrounding coat. The sensor was connected *via* cables to the Smart Sensor slots of the recording device affixed to the harness handle as previously described. The AMG signal from the muscle was transmitted to the recording device then streamed *via* Wi-Fi signal to a hand-held computer tablet (iPad, Apple Inc., Cupertino, CA, USA). The muscle signals could be evaluated and visualized in real time to ensure appropriate transmission of recordings from the sensors.

The dogs were walked and trotted over the pressure-sensitive walkway by the same person (MAW) and gait and muscle data were collected concurrently. The authors chose to rest the dogs between each new set of muscle sensors (average 21.3 min) both to more closely mimic the stop-start of hunting, but also to avoid any possible effects of warm up. This was done in addition to randomizing the order of AMG collection under different weight conditions. On average, the dogs were studied for 4–5 h, with frequent breaks between data sets. The AMG recordings were taken from each of the dogs at a walk and at a trot with no mouth weight, carrying a 1 lb (0.45 kg) mouth weight, and carrying a 3.2 lb (1.45 kg) mouth weight while moving over the walkway. Order of evaluation with weights was randomized. During each weight evaluation, the order of muscle pairs measured was also randomized. Three data recordings for each gait and mouth weight were saved and accepted when the dog walked or trotted across the pressure-sensitive walkway in a straight line holding the mouth weight during the full duration of the walk while the AMG sensors were recording. Dogs could hold the mouth weight anywhere on the body of the mouth weight and were allowed to readjust the bite hold only if it was at the very beginning or very end of the walkway (where data were not recorded) allowing for measurement of three full gait cycles while carrying the weight with no change of bite interruptions. Dogs were not allowed to hold the mouth weight by the string nor were they allowed to drop the mouth weight and pick it back up for the duration of the recorded walk or trot.

The AMG frequency and amplitude were calculated following the protocol by Varcoe et al. (13). During analysis of the AMG muscle data, the threshold was set at 0.2 and adjusted when scores were 0 or 10 (maximum value). Additional set parameters for analysis included a maximum frequency (max T) of 160 Hz (12). This is the maximum firing frequency detectable (22).

Gait data collection

Gait data were transmitted from the pressure sensitive walkway to the proprietary designated software for analysis as described above in the inclusion criteria. The dogs were encouraged to keep a steady speed and a straight line across the walkway. Passes were excluded if the dogs stepped off the pressure-sensitive walkway, changed gait, or had an inappropriate acceleration or deceleration (>10% variability in speed). Speed was evaluated within each dog at walk and trot to assess for any variability in speed between passes. Three valid walk and trot data sets consisting of three full gait cycles were analyzed per gait and per mouth weight. Temporospatial parameters and pressure measurements analyzed included total pressure index (TPI), step length (cm), and stance time (seconds). Comparison of the gait parameters of step length and stance time was made prior to AMG data collection with and without the harness and equipment to rule out any effect of the equipment (shaved hair, AMG sensor, gel, and adhesive) on step length and stance time, subsequently gait data used was that collected with the harness and equipment in place.

Statistical analysis

Normality was determined using a Shapiro-Wilks test. Data were analyzed on a dedicated statistical program (Prism 8, Graph Pad Software, San Diego, CA, USA) using a linear mixed model. The dependent variables were E, S, or T score, independent variables were weight and gait, and muscle, with a random effect of dog. *Post-hoc* tests being Šídák's multiple comparisons test for the AMG data and Tukey's multiple comparison test for the gait data. Gait data at 0 lb mouth weight was also compared with and without wearing AMG equipment. Significance was set at $p < 0.05$.

Results

Included dogs

A total of 10 dogs met the inclusion criteria for the study, 8 were Labrador Retrievers, 1 Flat Coat Retriever, and 1 Golden Retriever. Average body weight was 65.04 pounds (29.55 kg) and the average body condition score was 5.3 out of a 9-point system (5 is ideal body condition score) (Nestle PURINA Body Condition System). There were four male intact dogs, three male neutered dogs, two female spayed dogs, and one intact female dog. Each dog was involved in at least one of the following sports: seasonal waterfowl or upland hunting (N = 4), rally obedience (N = 3), hunt test (N = 4), field trial (N = 1), dock diving (N = 1), agility (N = 1), and shed dog hunt (N = 1). One of the dogs participated in four of the listed activities, two dogs participated in two, and the seven other dogs participated in one of the previously mentioned sports. Three of the 10 dogs were not considered to be regularly trained in retrieving (sports-specific fitness) at the time of evaluation as they were practicing retrieves once a week or less (23).

AMG data

Biceps muscle

There was no significant effect of weight on E, S, and T-score at the trot or the walk.

Triceps muscle

There was no significant effect of weight on E, S, and T-score at the trot or the walk.

Deltoideus muscle

There was no significant effect of weight on E, S, and T-score at the trot or the walk.

Brachiocephalicus muscle

There was no significant effect of weight on E, S, and T-score at the trot or the walk.

Between muscle comparison

E-score

At the trot, E-score was significantly lower in the deltoideus at the 3.2 lb (1.45 kg) mouth weight vs. the brachiocephalicus ($p = 0.03$) and the deltoideus vs. brachiocephalicus at the 1 lb (0.45 kg) mouth weight ($p = 0.04$). There was no significant effect between muscle responses to increasing mouth weight at trot for E-score ($p = 0.78$) (Figure 2).

At walk, there was a significant effect of muscle-to-mouth weight comparison on E-score ($p = 0.01$) overall, with three of

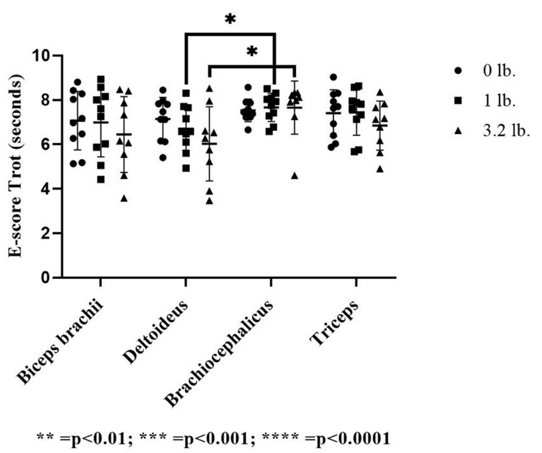

FIGURE 2
Acoustic myography (AMG) efficiency score (E-score) at trot in the biceps brachii, deltoideus, brachiocephalicus, and triceps (*N* = 10). The asterisks denote different levels of significance. The asterisks denote different levels of significance (*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$, ****$P \leq 0.0001$).

the four muscles (biceps, brachiocephalicus, triceps) decreasing in E-score with increasing weight; however, *post-hoc* testing did not determine pairwise differences likely due to power issues with a conservative *post-hoc* test and a higher number of comparisons. The overall mixed model significance was likely driven by the E-score of the deltoid muscle 0–1 lb ($p = 0.06$), and the triceps 1–3 lbs ($p = 0.07$). There was no significant effect of muscle ($p = 0.33$) or weight ($p = 0.06$) on E-score (Figure 3).

S-score

There was no significant effect of muscle ($p = 0.22$), weight ($p = 0.19$), or between muscles with increasing mouth weight ($p = 0.59$) on S-score at a trot. At walk, the S-score was significantly lower in the biceps ($p = 0.04$) and the triceps ($p = 0.02$) vs. the brachiocephalicus at 0 lb mouth weight. With the addition of 1 lb (0.45 kg) mouth weight, the S-score in the biceps was significantly lower than the brachiocephalicus ($p = 0.03$). There was no significant effect of mouth weight ($p = 0.85$) or between muscle responses to increasing mouth weight for S-score ($p = 0.38$) (Figure 4).

T-score

There was a significant effect of muscle on T-score at a trot ($p \leq 0.01$); however, no individual muscle comparison was significant; comparing the biceps and the brachiocephalicus at the 0 lb vs. the 1 lb (0.45 kg) mouth weight was approaching significance ($p = 0.05$) with the biceps having a lower T-score. There was no significant effect of weight ($p = 0.17$) or between muscle responses to increasing mouth weight for T-score ($p = 0.61$) at the trot.

At the walk, the T-score was significantly lower in the triceps vs. the brachiocephalicus at 0 lb ($p \leq 0.05$) and in the biceps vs.

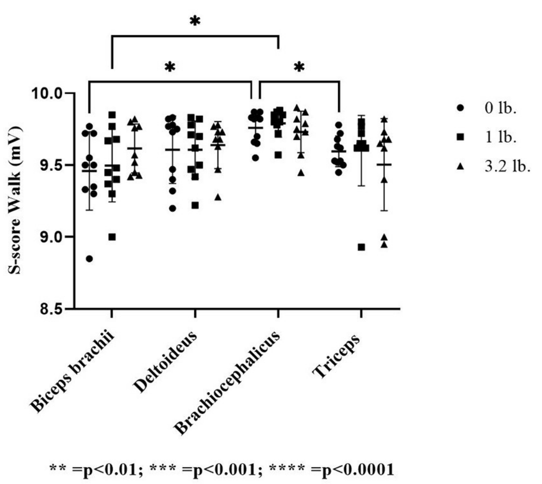

FIGURE 4
Acoustic myography (AMG) spatial summation score (S-score) at the walk in the biceps brachii, deltoideus, brachiocephalicus, and triceps ($N = 10$). The asterisks denote different levels of significance. The asterisks denote different levels of significance (*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$, ****$P \leq 0.0001$).

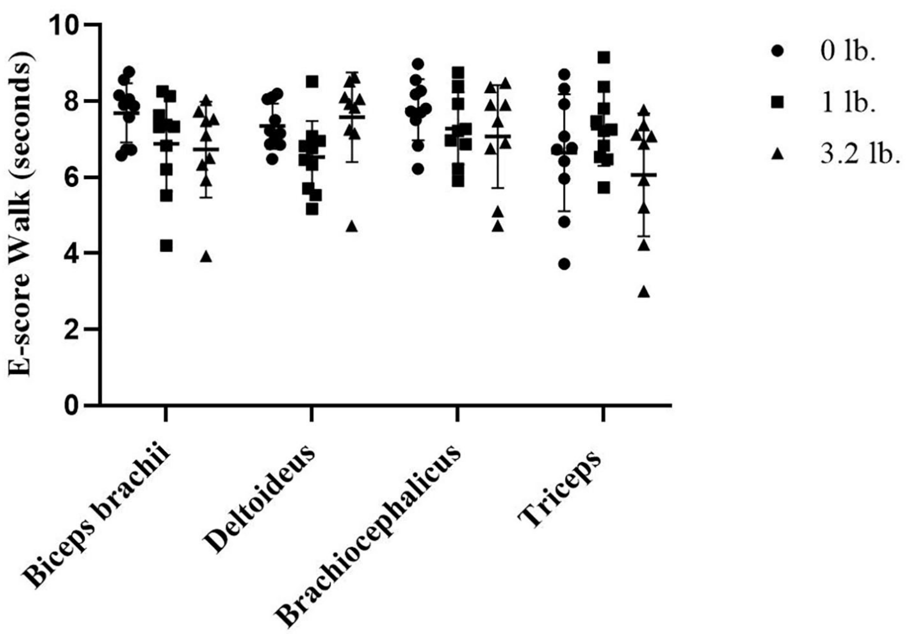

FIGURE 3
Acoustic myography (AMG) efficiency score (E-score) at walk in the biceps brachii, deltoideus, brachiocephalicus, and triceps ($N = 10$).

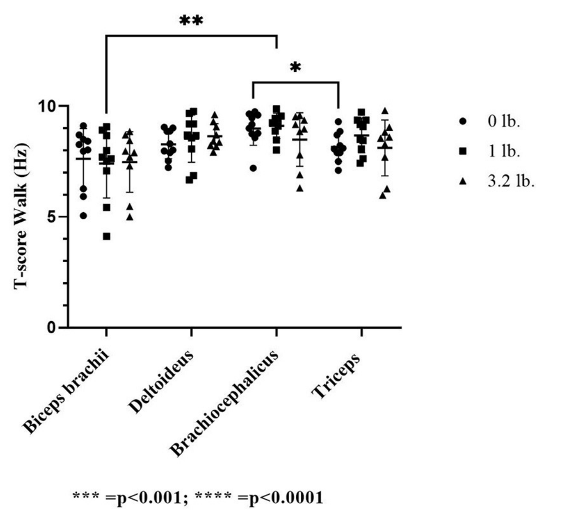

FIGURE 5
Acoustic myography (AMG) temporal summation score (T-score) at the trot in the biceps brachii, deltoideus, brachiocephalicus, and triceps ($N = 10$). The asterisks denote different levels of significance. The asterisks denote different levels of significance ($*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$, $****P \leq 0.0001$).

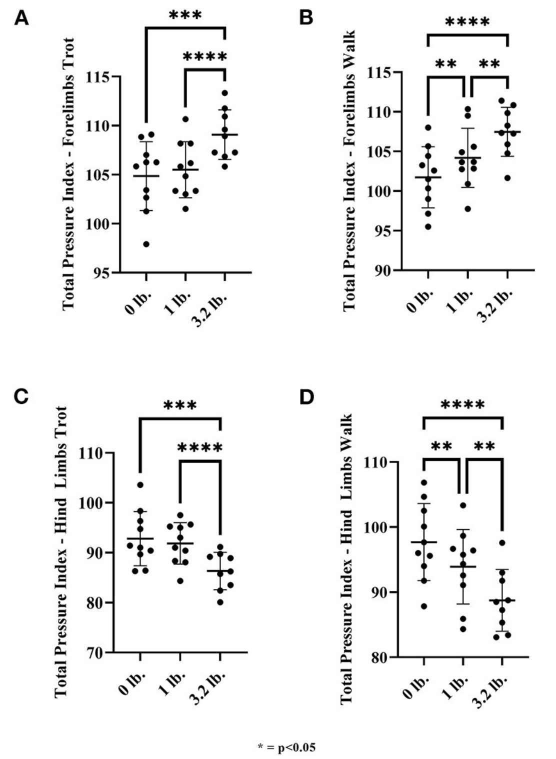

FIGURE 6
Total pressure index for front and hind limbs at walk and trot. **(A)** Front limb trot, **(B)** Front limb walk, **(C)** Hind limb trot, and **(D)** Hind limb walk ($N = 10$). The asterisks denote different levels of significance ($*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$, $****P \leq 0.0001$).

the brachiocephalicus with the 1 lb (0.45 kg) weight ($p \leq 0.01$). There was no significant effect of weight ($p = 0.54$) or between muscle responses to increasing mouth weight for T-score ($p = 0.68$) at the walk (Figure 5).

Gait data

At trot, each individual dog was consistent in speed under different conditions of weight, with a less than 10% variability in speed between all passes on the walkway. At the walk, speed of each individual dog showed more variation, with a maximum of 13% variation in speed between different passes; there was no pattern between weight carried and speed.

There was no significant difference in step length ($p > 0.27$) and stance time ($p > 0.13$) at the walk and trot with and without the harness and equipment, gait data analyzed was that collected with harness and equipment.

TPI

There was a significant effect of mouth weight on TPI in the forelimbs at trot for 0 vs. 3.2 lb (1.45 kg) ($p < 0.01$) and 1 lb (0.45 kg) vs. 3.2 lb (1.45 kg) ($p < 0.01$), with increased total pressure through the forelimbs with the higher weight in each case. There was a significant effect of mouth weight at a walk with 0 vs. 1 lb (0.45 kg) ($p < 0.01$), 0 vs. 3.2 lb (1.45 kg) ($p < 0.01$), and 1 lb (0.45 kg) vs. 3.2 lb (1.45 kg) ($p < 0.01$) with increased total pressure through the forelimbs corresponding to higher weight in all cases (Figure 6). The change in weight between 0 and 1 lb (0.45 kg) at the walk was greater than at the trot between those weights, with a 1.4-fold larger change at the walk vs. the trot [mean TPI changed 2.45 units from 0 to 1 lb (0.45 kg) at walk and 0.65 units from 0 to 1 lb (0.45 kg) at trot]. Similar changes were identified between 0 and 3.2 lb (1.45 kg) with a 1.3-fold larger change at the walk (5.7 units walk, 4.2 units trot).

There was a significant effect of mouth weight at trot with 0 vs. 3.2 lb ($p < 0.01$) and 1 lb (0.45 kg) vs. 3.2 lb (1.45 kg) ($p < 0.01$) on hindlimb TPI at trot, with hindlimb TPI being lower with the higher mouth weight. There was a significant effect of mouth weight at a walk with 0 vs. 1 lb (0.45 kg) ($p < 0.01$), 0 vs. 3.2 lb (1.45 kg) ($p < 0.01$), and 1 lb (0.45 kg) vs. 3.2 lb (1.45 kg) mouth weight ($p < 0.1$) with the hindlimb TPI being lower with increasing weight (Figure 6).

Step length

There was no significant effect of mouth weight on step length at the trot in the forelimbs ($p = 0.23$). At walk, there was a

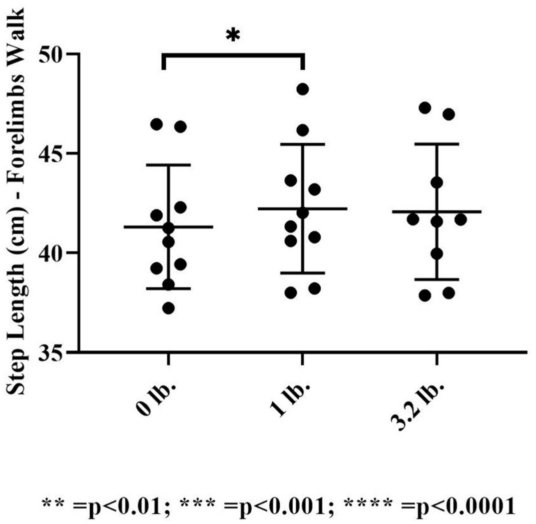

FIGURE 7
Step length at the walk ($N = 10$). The asterisks denote different levels of significance (*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$, ****$P \leq 0.0001$).

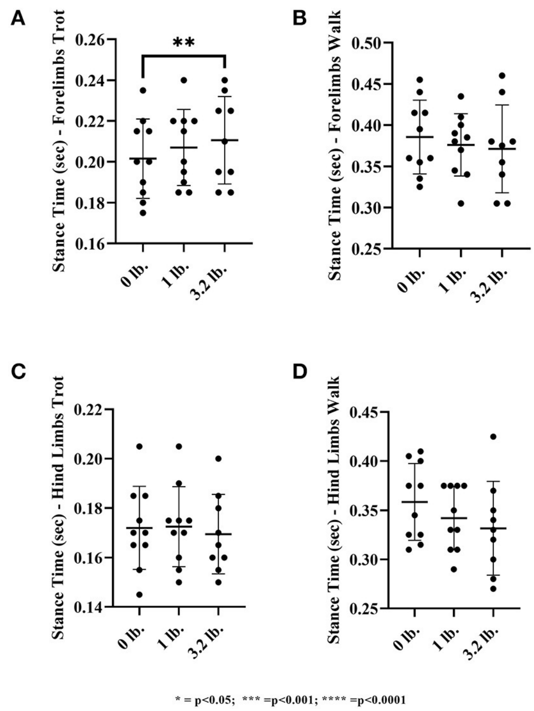

FIGURE 8
Stance time of the front limb and hind limbs at walk and trot. **(A)** Front limb trot, **(B)** Front limb walk, **(C)** Hind limb trot, **(D)** Hind limb walk ($N = 10$). The asterisks denote different levels of significance (*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$, ****$P \leq 0.0001$).

significant effect of mouth weight on step length in the 0 vs. 1 lb (0.45 kg) mouth weight ($p = 0.02$), showing an increase in step length with the 1 lb (0.45 kg) mouth weight.

There was no significant effect of mouth weight on hind limb step length at the trot ($p = 0.11$) or the walk ($p = 0.1$) (Figure 7).

Stance time

There was a significant effect of mouth weight on stance time at the trot in the forelimbs ($p = 0.03$), showing increased stance time with higher weight, but this was not present at the walk ($p = 0.27$). At the trot, there was significantly longer stance time with the 3.2 lb weight than with 0 lb ($p < 0.01$). There was no significance with the 1 vs. 3.2 lb mouth weight ($p = 0.45$), the 0 vs. 1 lb mouth weight was approaching significance with a trend to longer stance time with 1 lb ($p = 0.05$).

There was no significant effect of mouth weight on stance time at the trot in the hind limbs ($p = 0.11$). There was an overall significant effect of mouth weights at the walk ($p = 0.03$) in the hindlimbs but no significant difference when weight combinations were further evaluated individually (Figure 8).

Discussion

There was no significant effect of mouth weight within any individual muscle; however, there was a significant effect when evaluating the muscles compared with each other. We compared AMG scores between muscles as well as the changes within a muscle under different conditions of weight because we wanted to see if the relative workload increased in one muscle vs. the others. Uneven workload in the shoulder muscles could be a relative risk factor for muscle injury in the biceps. This choice is not unprecedented as previous studies in people using electromyography (EMG) have compared the activity of different muscles during exercise (24, 25). In this study, the brachiocephalicus showed less action than the other three muscles due to gait and not weight. The function of the deltoideus changed the most in comparison to brachiocephalicus in response to mouth weight; however, it did not show a significant change in comparison to its baseline function. We anticipated that the biceps would have greater muscle fiber recruitment (spatial summation) in response to mouth weight, but it did not. Therefore, we reject our hypothesis that carrying a mouth weight would result in greater recruitment of the biceps brachii, triceps, and deltoideus muscles but not the brachiocephalicus in retriever hunting dogs at walk and trot.

The TPI in the forelimbs at both the walk and trot increased with increasing mouth weight. However, information about stance time and step length was variable. Step length was longer with increasing weight, but only significant at the walk when comparing 0–1 lb (0.45 kg). Stance time was increased but only significant at the trot between 0 and 3.2 lb (1.45 kg). This resulted in our hypothesis that step length and stance time would be decreased in the forelimbs when carrying a mouth weight being rejected.

Similar to Bockstahler et al. (4) pressure-sensitive plate data, the present study found that TPI was significantly increased in the forelimbs and reduced through the hind limbs at the walk with increasing mouth weights. Our significant findings of an increase in step length in the forelimbs at walk between 0 and 1 lb (0.45 kg) differ from the findings of Bockstahler et al. (4), where the forelimb step length was actually longer with no weight compared to all other conditions of mouth weights. There is no clear explanation for this difference in findings. The difference between mean step length at 0 and 1 lb is only 1 cm and so is unlikely to be biologically significant, Bockstahler found a larger (6 cm) mean difference in step length between no weight and the highest weight carried (4 kg). In contrast to our findings of no change in hind limb step length in response to weight, the Bockstahler study (4) found hind limb step length decreased when carrying a 4 kg (8.8 lb) mouth weight; however, the maximum weight we used was 3.2 lb (1.45 kg) which may explain the disagreement for both forelimb and hind limb step length. The weights chosen in the present study were practical for the dogs to carry at trot and correlated to the most common bird sizes retrieved in the United States.

The trot was chosen for this study to help better understand dogs moving at a greater speed, i.e., to cover ground when hunting, recognizing that the gaits have their own biomechanical differences. The lack of change in step length in response to weight at this gait may be because trot is an efficient gait, using energy from elastic storage potential (26) so this could reduce the need for muscle activation; however, a trotting gait has been shown to produce more force through the limbs than a walk (21, 26). A change in muscle function in response to weight carried in the mouth may be more detectable at a canter or gallop, which is the usual natural retrieving gait, but this was not practical for gait analysis.

The main focus of this study, having confirmed increased TPI through the forelimbs in response to mouth weight, was to explore the effect of this increased pressure on muscle function. Overall, the AMG data were supportive of low muscle fiber recruitment, low frequency, and duration of contraction in the brachiocephalicus, both without and with mouth weight. The low muscle activity of the brachiocephalicus (with no weight) is in support of previous studies, which showed that there was low muscle activity of the brachiocephalicus at a constant trotting speed (7) and no difference in function between walk and trot (10) as measured *via* electromyography (EMG). In a study where weight was added to the carpus, (7) brachiocephalicus activity was 313 times greater than baseline, contrasting our findings of mouth weight having no detectable influence on the function of this muscle despite an increase in force through the forelimbs (TPI). Because brachiocephalicus is a forelimb protractor, it is mostly active during early to middle swing phase, though it is active during the last third of stance (8). With the bulk of brachiocephalicus activity being during swing, a weight affixed to the carpus would likely produce resistance to protraction, whereas a mouth weight may not have as much direct effect.

Previous biomechanical studies (8) have found that the biceps brachii tendon of origin is a shoulder stabilizer as part of a shoulder locking mechanism during stance with compression of the supraglenoid tubercle along with tension in the caudal joint capsule, limiting translation (9), the biceps tendon also limits translation of the joint in flexion (27). This constraining action is not dependent on muscular action in the biceps (12, 27). Shoulder flexion may apply tensile stress on the tendon of origin of the biceps, as flexion translates the glenoid cavity caudally in relation to the humeral head (12). The active time period in the biceps muscle as recorded *via* electromyography (EMG) at the trot is only 30% of the gait cycle, vs. 57% at a walk (8). The muscle is most active during walk in the latter two thirds of stance and the first 40% of swing, whereas at trot it is active in the latter half of stance and only 7% of early swing (8). Biceps fiber recruitment (S-score) was significantly greater than brachiocephalicus at the walk without weight (control status), as well as with the 1 lb (0.45 kg) weight, and this was not seen at trot, indicating that this greater fiber recruitment is likely due to longer duration of muscle activation the walking gait. We did find significantly greater frequency of contraction (lower T-score) in the biceps as compared to brachiocephalicus at the walk, but not trot, when carrying 1 lb (0.45 kg), and this could be an effect of carrying mouth weight. At trot, only 26% of the work of locomotion is contracting muscles, the rest being from elastic recoil (26). Knowledge of duration and timing of biceps activity at both gaits and of gait efficiency explains the lack of detectable difference when compared to brachiocephalicus at trot. Even if there was a difference in function of the biceps brachii with increasing weight, it may not be clinically relevant at the trot. At gallop, a gait used when retrieving, 56% of the energy of locomotion was found to be actively shortening muscles, but the hindlimb muscles perform most of that work (26). If the shift in weight distribution found at walk and trot found in the current study holds, then we can expect work to increase in forelimb muscles in response to mouth weight at this gait. However, at the gallop, the biceps brachii is activated for even less of the stride than at trot, at 23% of the total stride time (8); therefore, this could have further challenged our ability to detect a difference in biceps function.

Overall, there was a decrease in the numeric value of E-score at the trot with increasing mouth weights in the biceps, deltoideus and triceps muscles as weight increased, but not in the brachiocephalicus. The deltoideus acts to flex the shoulder joint and plays a minor role as one of the dynamic shoulder joint stabilizers (9). Significantly lower E-score (increased duration of contraction compared to relaxation time in the muscle) was seen in deltoideus at trot when compared to brachiocephalicus at both 1 lb (0.45 kg) and 3.2 lb (1.45 kg). Shoulder flexion is also greater at the trot than at the walk (8) and this is the gait where we found a significant change in deltoideus E-score; however, the greater relative amount of muscle contraction could instead reflect a stabilizing function (9). There is no available previously published myographic data on deltoideus action in the dog, but the muscle should be active in the last half of stance to early swing phase, mirroring published action in the latissimus dorsi which also flexes the shoulder (8). The longer stance time seen in response to mouth weight at the trot should have increased the deltoideus contraction time over the muscle's baseline, which could apply tensile stress on the biceps tendon; however, this was not seen (9).

The triceps muscle is an anti-gravity muscle that braces the elbow into extension during stance phase. We chose the triceps as it is an antagonistic muscle to the biceps (8). There are two main phases of activity of the triceps (8). First, the triceps muscle begins to activate during late swing to touch down. One would think that we would see additional triceps action with increased mouth weight, correlating with increased forelimb TPI but we did not see those AMG changes. The triceps did contract more frequently compared to the brachiocephalicus with no mouth weight. The second phase of triceps contraction begins after a pause in late stance, just before liftoff, ending halfway through swing to help retract the elbow. At trot, the stance phase is shorter and the activation of triceps is shorter. With this efficient gait, this could be why we did not see a change in muscle activity with the triceps in response to weight. The triceps is active for the longest period of time during the gait cycle compared to the biceps and the brachiocephalicus (8) and there is no such data on timing of muscle contraction in the deltoideus.

As more weight (greater TPI) is put through the front limbs with increasing mouth weight, there is a possibility for muscle fatigue in structures not evaluated in this study which could in turn overload the biceps muscle and tendon. Overload of a tendinous structure secondary to fatigue of another structure has been noted in other species to result in tendinopathy (28). This brings the consideration that dogs are becoming fatigued or have inadequate recovery time between events or hunts thus overloading the biceps tendon. Biceps tendinopathies may have nothing to do with biceps muscle contraction but may be due to relative overload, when another structure fatigues.

Potential limitations include a smaller number of dogs evaluated which may have contributed to not reaching statistical significance despite dogs having a lower E-score in the biceps, triceps, and deltoideus muscles with increasing weight. This is pertinent considering the results showed a trend toward a lower E-score at trot in response to increasing mouth weight in the biceps, triceps, and deltoideus muscles, the lack of significant findings may be due to the test being underpowered. Low test power is also a consideration for comparison of the biceps and brachiocephalicus T-score at trot, as the biceps had a numerically lower T-score approaching significance under both 0 and 1 lb (0.45 kg) conditions. Longer stance time with the 1 lb (0.45 kg) vs. 0 lb weight was also approaching significance.

Other limitations include that we did not assess dogs on field surfaces, under prolonged muscle work, and we only evaluated at the walk and trot. The dogs evaluated were all fit, and less fit dogs might be more prone to injury. We were not able to reproduce field conditions, prolonged muscle work was not possible and a walking or trotting gait is not fully reflective of working retriever dogs who normally gallop when carrying a bird. It could be considered another limitation that these dogs were all fit, whereas some dogs may not have a similar level of fitness when carrying birds in the field and it brings to question that the muscle changes in our test subjects may not be fully representative of those dogs prone to biceps injury.

It may have been that muscle function could be altered by warm up as the test progressed for each dog. In the article by Fuglsang-Damgaard et al. (29), they evaluated the triceps muscle activation in agility dogs using AMG during warm up exercises. What they found was the triceps muscle recruited fewer muscle fibers (S-score) and had less duration of contraction (E-score) after warm up. We rested each dog after each pass over the gait mat as that data was being briefly analyzed, dogs were also rested as we transitioned between pairs of AMG sensors. The randomized order of mouth weights should have dealt with the warm up concern, but it may not have been fully avoided.

Not all dogs held the mouth weights in the center and some dogs made bite adjustments; when the bite adjustments were subjectively significant or the position of the mouth weight caused an observably large head tilt, these data sets were excluded. Speed varied between individual passes over the mat for each individual dog and was more variable at walk than at trot, though this variability was a maximum of 13% (due to two dogs the investigators could not get less variable). More than 10% variability in speed at the walk could have affected the force placed on each limb and therefore how the muscle works; however, it was a challenge to get the dog to accept the mouth weight during a walk pass over the mat, which resulted in more variation between passes. Lastly, it is possible that the presence of the harness holding the recording device restricted shoulder motion and therefore affected results. A similar harness to the one used in this study was found to restrict shoulder extension by approximately 2° at walk and by 5° at trot (30). That harness also passed across the chest (though the harness sat directly across the humeri rather than proximal to the humerus as in the case of the harness used in this study). Restriction of shoulder extension could have inhibited brachiocephalicus action; however, the same restriction would be true for all dogs under all experimental circumstances.

The results show that biceps brachii muscle activity did not change significantly in correlation to increased mouth weight. Additional studies are warranted to further evaluate the biceps and additional shoulder muscles in response to mouth weights.

Data availability statement

The datasets presented in this article are not readily available because data values are included in the graphs within the manuscript. Requests to access the datasets should be directed to drmissy@tcrehab.com.

Ethics statement

Ethical review and approval was not required for the animal study because the study was non invasive and participants underwent no medical intervention. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

MW worked in conjunction with JT in study design, data collection, and analysis. JM contributed to the study design and the grant proposal and assisted MW in running statistical analyses. JT and MW wrote the manuscript with additional input from JM in article editing and proofing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.983386/full#supplementary-material

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Effects of jump height on forelimb landing forces in border collies

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Objective: The objective of this study was to evaluate the effects of jump height on the landing forces of dogs.

Animals: Client-owned Border Collies experienced in agility competition, $n = 9$.

Procedures: The study involved client owned border collies with the same AKC standard jump height of 20 inches and preferred height of 16 inches. Standard height is based upon the height of the dog at the withers, with preferred height referred to as reduction in jump height by one level due to injury or age. An AKC regulation bar jump was placed over a previously validated pressure sensitive walkway (PSW). The peak force (%BW) and peak contact pressure (kPa) of the leading and trailing forelimbs were evaluated for all dogs.

Results: There was no significant difference in landing force between the two jump heights for either peak force as a percentage of body weight or peak contact pressure when evaluated in both leading and trailing forelimbs.

Conclusions and clinical relevance: Our findings demonstrated no significant difference in active landing forces of peak contact pressure and peak force on the forelimbs of dogs when jumping at a standard jump height vs. a preferred jump height when controlling for velocity in dogs performing a single running bar jump. These results suggest that the recommendation of decreasing jump height for older animals or injured animals may not provide a significant decrease in the impact on the forelimbs. It is likely that other factors contribute to the total forelimb kinematics picture during competition. Veterinarians and trainers should consider additional ways to decrease impact for canine athletes as they recover from injury.

KEYWORDS
agility, jump height, bar jump, landing force, peak force, peak contact pressure

Introduction

Participation in sporting activities such as agility competitions has become increasingly popular with dog owners. There are over 1 million entries into dog agility competitions sponsored by the American Kennel Club (AKC) yearly. Agility competition is a team sport in which a handler directs a dog through a series of obstacles such as jumps, weave poles, A-frames, and tunnels. The dogs are required to sprint, jump, turn abruptly, balance on narrow plank widths at speed, run over and tip a see-saw, weave back and forth through the gaps between poles set in a straight line, and ascend and descend a steep ramp. Dog and handler teams are rewarded for speed and accuracy.

Given the highly athletic nature of this sport, injuries are common in agility dogs. Recently, it was reported that up to 42% of agility athletes sustain an injury during their career, with the forelimbs commonly affected and reported in up to 60.5% of cases (1–4). The shoulder has been reported to be the most common location of injury for these dogs with injury reports ranging from 12.9 to 30.1% (1–4). Literature also reports that most injuries occurred during obstacle performance during competition, with most injuries (16.9–36.5%) occurring when traversing the bar jumps, which are the most numerous obstacles on any agility course (3, 5).

In both veterinary sports medicine and agility training a common recommendation is to decrease the jump height for dogs that have sustained an injury or are advanced in age. Jump heights used in competitions are standardized based upon the height of the dog at the withers (the dorsal aspect of the scapula). Based on AKC published regulations for bar jumps, there are seven different standard jump heights including 4, 8, 12, 16, 20, and 24 inches. Regulations published for preferred height are defined as jump heights set at 4, 8, 12, 16, and 20 inches based on a drop of a one level from the dog's standard jump height, thus one level would equate to a 4 inch difference in height. The recommendation to decrease jump height is based on the belief that doing so will help to reduce the impact placed on the forelimbs of the dog when landing. When a dog is moved down in jump height by one level, this is termed their "preferred" height by the AKC (6).

Little research has evaluated the kinetics of impact associated with jumps of variable heights used in agility competitions. A limited study of 11 agility dogs evaluating the effect of different jump obstacles on approach speed and landing angle, found that increased vertical forces occurred during the hurdle (vertical) jump compared to the broad (horizontal) jump (5). A recent study assessed the impact of static jumping on landing forces, and found a significant difference in peak vertical forces when landing from a box set at different heights (7). However, no assessment of active landing force over a single bar jump associated with a running jump has been assessed. The effect of varying jump heights has been demonstrated to affect the jump kinetics and kinematics of dogs including approach velocity, jump trajectory, and joint angles as hurdle height increased, but landing forces were not evaluated.

The aim of this study was to evaluate the kinetics of landing on the forelimbs of dogs in a setting simulating training and competing using a single vertical jump of differing heights. We hypothesized that there would be no significant difference in the forces exerted on the forelimbs of the dog upon landing between standard and preferred heights.

Materials and methods

Healthy Border Collies ($n = 9$) with at least 1 year of experience in agility competition were enrolled in the study with written owner consent and IACUC approval. Border Collies were chosen based on this breed being one of the most common breeds of dogs competing in agility, as well as this breed having a reported increased risk for injury in agility training or competition (1, 2, 4). To control for other variables, all participants had the same AKC standard bar jump height of 20 inches, and preferred height of 16 inches. For this reason, only dogs >18 inches and under 22 inches at the withers were eligible to participate in this study. All dogs were measured from the ground to the dorsal aspect of the scapula (withers) to confirm height and jump category. Prior to participating in the study, all dogs underwent a complete physical examination including orthopedic and neurologic exam, by an experienced veterinarian board-certified in both surgery and sports medicine and rehabilitation (NK). Dogs with orthopedic or neurologic disease were excluded.

An AKC regulation bar jump[1] was placed over a previously validated pressure sensitive walkway (PSW) (6).[2] To consistently regulate speed and velocity of the dog during the approach phase, five ground poles ($5'$ long, $1''$ diameter PVC poles elevated $3''$ from the ground) were placed along the runway in front of the bar jump (Figure 1). The distance between the ground poles was set at 50 inches, with the last ground pole placed 60 inches from the bar jump correlating to the preferred jump spot of the dog, with the bar jump situated centrally over the PSW. These distances were determined during a previous pilot study where video recorded trials of participants running over the ground poles at different intervals were evaluated to determine what distance between poles allowed for a consistent, moderate-speed approach of the dogs.

Dogs were allowed to habituate to the room, the walkway and ground poles, and the bar jump. All dogs completed 10 video-recorded trials for both standard and preferred heights. The starting height (standard vs. preferred) was randomly assigned for each dog *via* coin toss. All dogs were given a minimum of 15 mins rest between jump heights. Owners were positioned at the end of the mat facing their dog, with the dog positioned in the typical pre-run agility stance. Trials were considered valid if there was no clear turning of the head from midline, full clearance of bar jump with no contact, and

1 "Regulations for Agility Trials" published by The American Kennel Club, amended February 1st, 2016.

2 HRV WalkwayTM 6 VersaTek System, Tekscan Animal Walkway System, South Boston, MA.

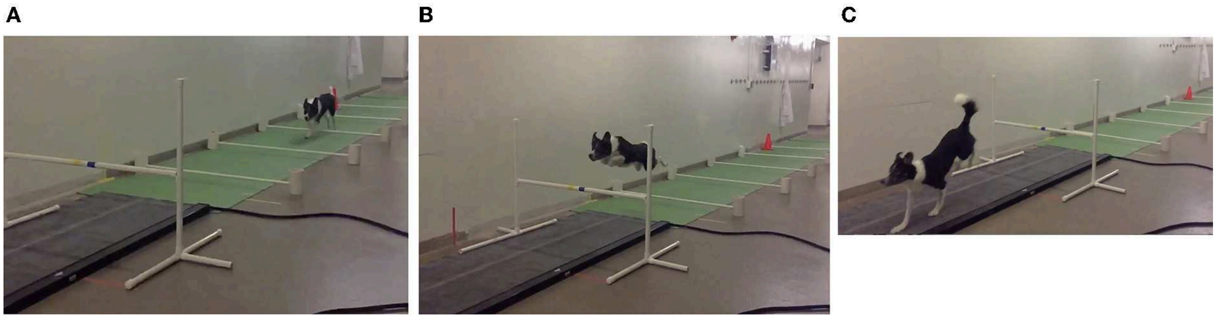

FIGURE 1
Images of bar jump and PSW set-up. An AKC regulation bar jump (see footnote 1) was placed centrally over a pressure sensitive walkway (PSW) (see footnote 2). Five ground poles spaced 50 inches apart were placed along the runway in front of the bar jump that were three inches above the ground. During the run, the dog jumps between each of the ground poles **(A)**, before taking off between the last ground pole and the regulation bar jump **(B)**, and landing on the PSW **(C)**.

both forelimbs landed completely on the PSW. Data from the first five valid trials for each height was averaged and used for statistical analysis.

The peak force (N), defined as maximum vertical force recorded during landing, and peak contact pressure (kPa), defined as maximum force per unit area upon contact of the forelimb, of the landing forelimbs were evaluated for all dogs. Data were assessed for both the first landing foot (defined as the trailing limb) as well as the second landing foot (or the lead limb), and as an average of both landing feet. Data were normalized to body weight. Peak force as a percentage of body weight (%BW) and peak contact pressure (kPa) measurements between heights were compared using a paired *t*-test (Prism v7.0, GraphPad Software, Inc). Significance was set at $P < 0.05$. The average velocity on approach over the ground poles was calculated for all dogs and averaged using the video-recorded data and standard distance over the ground poles of 50 inches.

Results

Nine adult Border Collies were enrolled (5 male neutered, 2 female spayed, and 1 each male intact and female intact). Mean weight of the dogs was 15.9 ± 1.9 kg (range 12.7–18.8 kg), and mean age 4.9 ± 2.8 years (range 1–10 years). Mean height of the dogs measured from the ground to the dorsal aspect of the scapula was 53.0 ± 1.4 cm (range 51.2–55.6 cm). All nine dogs jumped at a standard height of 20 inches and preferred height of 16 inches. Mean velocity of the dogs was assessed from video footage. Mean velocity (distance/time) for all dogs was 33.73 ± 5.33 in/s (range 28–43.8 in/s).

There was no significant difference in landing force between the two jump heights for either peak force as a percentage of body weight or peak contact pressure. Mean peak force when averaging the forelimbs was 26.5 (%BW) for the 20″ jump height and 26.09 (%BW) for the preferred jump height (Figure 2). The means of these two groups was not statistically significant ($p = 0.4228$). When evaluating the peak force of the trailing forelimb, the mean peak force was 28.29 (%BW) for the 20″ jump height and 27.81 (%BW) for the preferred jump height (Figure 3). The means of these two groups was not statistically significant ($p = 0.7081$. When evaluating the peak force of the leading forelimb, the mean peak force was 24.83 (%BW) for the 20″ jump height and 24.11 (%BW) for the preferred jump height (Figure 4). The means of these two groups was not statistically significant ($p = 0.3537$). Mean peak contact pressure when averaging the forelimbs was 395.56 kPa for the 20″ jump height and 390.05 kPa for the preferred jump height (Figure 5). The means of these two groups was not statistically significant ($p = 0.6227$). When evaluating the peak contact pressure of the trailing forelimb, the mean peak contact pressure was 406.61 kPa for the 20″ jump height and 377.60 kPa for the preferred jump height (Figure 6). The means of these two groups was not statistically significant ($p = 0.8890$). When evaluating the peak contact pressure of the leading forelimb, the mean peak contact pressure was 393.07 kPa for the 20” jump height and 410.922 kPa for the preferred jump height (Figure 7). The means of these two groups was not statistically significant ($p = 0.2294$).

There was significant variability when evaluating consistency of forelimb lateralization for the leading and trailing forelimb. No dog consistently landed on either the right or left forelimb, whether evaluated at the standard or preferred height.

Discussion

The purpose of this study was to evaluate the effect of variation in jump height on the landing kinetics of forelimbs in agility dogs when performing a single vertical running bar jump. Our findings demonstrated that there was no significant difference in active landing forces of peak contact pressure

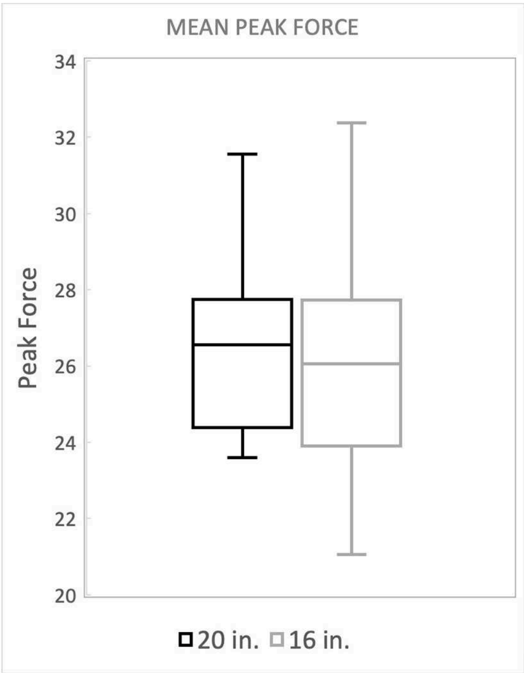

FIGURE 2
Mean peak force when averaging the forelimbs. There was no significant difference between the standard (20″) or preferred (16″) height for mean peak force of the forelimbs.

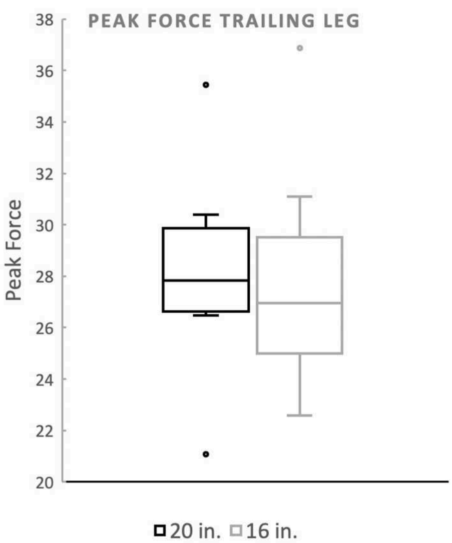

FIGURE 3
Peak force of the trailing forelimb. There was no significant difference between the standard (20″) or preferred (16″) height for the trailing forelimb. The dots noted outside the box plot are outliers.

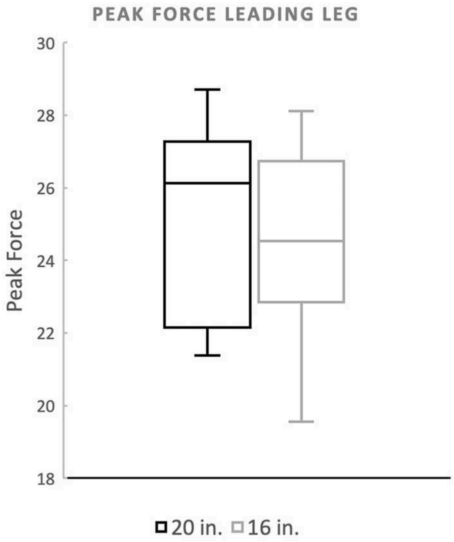

FIGURE 4
Peak force of the leading forelimb. There was no significant difference between the standard (20″) or preferred (16″) height for the leading forelimb.

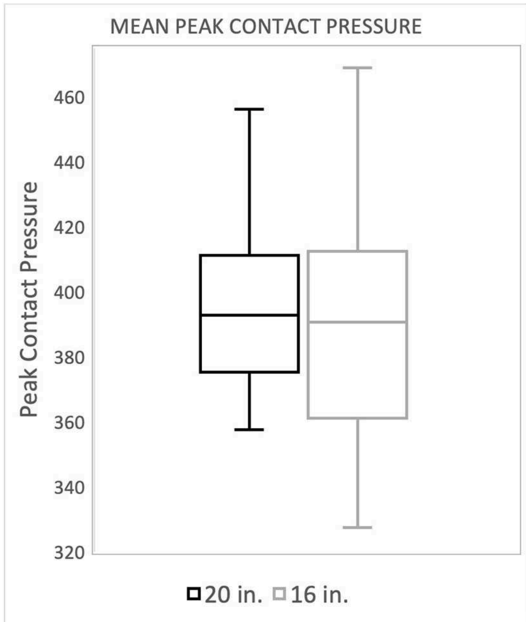

FIGURE 5
Mean peak contact pressure when averaging the forelimbs. There was no significant difference between the standard (20″) or preferred (16″) height when averaging both peak contact pressure of both forelimbs.

and peak force on the forelimbs of dogs when jumping at a standard jump height (20″) vs. a preferred jump height (16″ when controlling for velocity. These results suggest that the recommendation of decreasing jump height for older animals or injured animals when performing the running bar jump may not

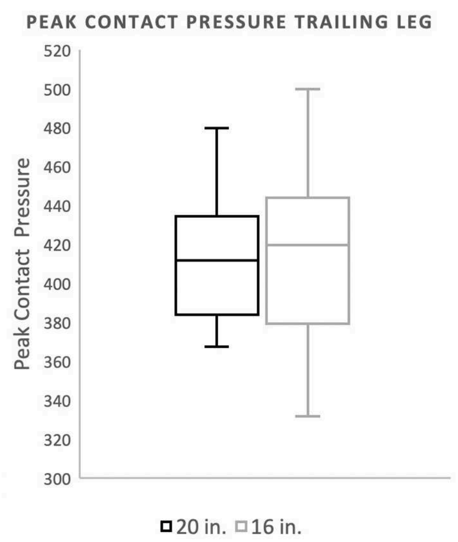

FIGURE 6
Mean peak contact pressure of the trailing forelimb. There was no significant difference between the standard (20″) or preferred (16″) height for the trailing forelimb.

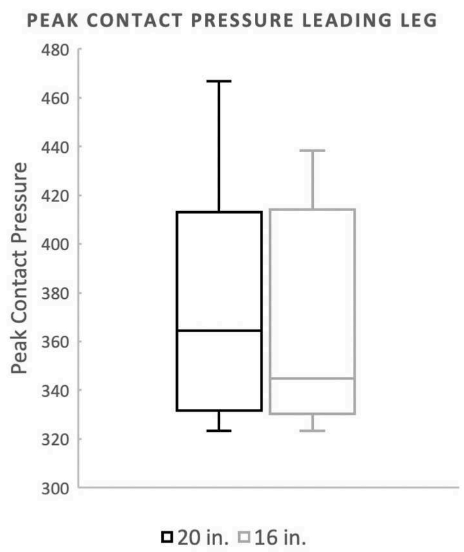

FIGURE 7
Mean peak contact pressure of the leading forelimb. There was no significant difference between the standard (20″) or preferred (16″) height for the leading forelimb.

provide a significant decrease in the impact on the forelimbs of these athletes, though additional studies are needed to confirm this theory.

The jump can be broken down into five phases—approach, take-off, aerial, landing, and departure (8, 9). During these phases, especially during the approach and take-off, the dog must have an appropriate velocity and distance to the obstacle to successfully clear it. The characteristics of the obstacle (including height) can affect these split-second decisions. Studies have demonstrated that as jump height increases there is significant change in joints angles of the forelimb and vertebral column, specifically increased flexion of the radiohumeral and scapulohumeral joints and increased flexion of the base of the neck (7, 10). A significant increase in the height of trajectory and decrease in speed was also found with increasing hurdle height (7). In theory, the longer landing distance for a higher jump height might be secondary to the increased propulsive forces required to clear the jump, resulting in a greater distance between the jump and the landing spot. In support, other studies found that as the height of the obstacle decreases, there is an increase in speed and shallower landing angles of the forelimbs (5, 10). Pfau et al. reported peak vertical force of 4.5 times body weight when landing at a high speed (5). Further, when jump heights were not changed, but distances between jumps was increased, there was an increase in speed coupled with shallower landing angles (11, 12). The change in aerial phase and joint angles due to height of the object would in theory increase the downward velocity and acceleration occurring at landing. While this study attempted to control the approach velocity *via* the use of ground poles, we did not specifically evaluate for changes in velocity and acceleration between standard and preferred heights during the jump trajectory based on limitations with the walkway and cameras, which could impact overall force interpretation. In addition, this study did not evaluate the amount of time under each force. It could be argued that dogs at differing jump heights may have differences in time under pressure, which could ultimately affect force interpretation. Both these concepts should be evaluated in future studies.

The aforementioned studies in conjunction with this study challenge the simple recommendation that reducing bar jump height will decrease injury in agility animals if landing forces have a major impact on injuries. This is the first study to evaluate changes in landing kinetics of peak active force and peak contact pressure during the landing phase when evaluating a single vertical running bar jump. To the authors' knowledge, this is also the first study to regulate approach speed at a consistent velocity when evaluating bar jumps heights in agility dogs. This is an important factor to control in order to obtain meaningful comparative data. This was effected by having the dogs run over ground poles prior to taking off for the bar jump, enabling us to eliminate approach velocity as a factor affecting landing force. Previous studies have not regulated the approach velocity, but rather allowed participants to approach at their own pace. While doing so likely mimics natural adaptations that dogs take when jumping variable heights, it makes it challenging to determine the effect of simply a change in jump height on the kinetics of landing.

The height of the obstacle will not only affect the approach and take-off phases, but also the velocity at impact. Previous studies evaluating jumping down from a stationary position at different heights showed increases in peak vertical ground reaction forces (vGRF) with increase in height (13). In that study, it was noted that the changes in peak vGRF were much smaller than the changes made in the height (13). This correlates with our findings that there is no significant difference in peak contact pressure and peak force on the forelimbs of dogs when jumping at a standard jump height vs. a preferred jump height, and that further investigation into other variables affecting the kinematics of jumping is necessary.

When landing from an obstacle such as the bar jump, the forelimbs are loaded asymmetrically (14). Previous studies of Border Collies noted a shift of weight distribution toward the forelimbs with increasing jump height when landing (5). Dogs generally have an ∼60:40 distribution of forelimbs compared to hindlimbs, with border collies specifically having a 58:42 distribution (5, 15–18). The forelimbs have a strut-like action through phases of jumping including take-off and landing (19, 20). During landing, this strut-like action is used to transfer vertical motion into horizontal motion. This results in differences between the leading and trailing forelimbs, with the trailing forelimb being stiffer than the leading forelimb (21). It has been theorized that dogs strike harder with the leading forelimb, but stay longer on the trailing forelimb when landing from a high jump (22). Dogs also primarily brake *via* the trailing forelimb (22). When comparing the lateralization of leading and trailing limb for this study, there was variability identified at both the standard and preferred jump heights. Evaluation of the valid trials runs revealed no consistency in which forelimb was the lead or trail limb for all dogs at both heights. Upon separate evaluation of the both the leading and trailing forelimbs, no significant differences were noted in either peak force or peak contact pressure between jump heights.

Limb stiffness, whether an excess or deficiency, has been associated with injury (23, 24). Excessive stiffness can result in injury to the bone, while a lack of adequate stiffness may result in soft tissue injuries, which are common in agility dogs (1–3, 25). Previous studies in both dogs and horses have shown that the experience of the dog had an impact on jump kinetics (20, 26). Experienced dogs had a higher limb stiffness, decreased limb compression, and higher limb length on landing. They also had a quicker change to propulsion from braking during landing than less experienced dogs. In this study we did not control for experience level in agility among participating dogs. The resultant landing peak force and peak contact pressure did not significantly differ with change in jump height, but it would be prudent to consider evaluating this in more experienced vs. less experienced dogs for better recommendations on the impact this may have on the forelimbs, especially the trailing forelimb.

While in this study, jump height alone had minimal impact on landing force, it is likely that other factors including approach angle, length of aerial phase, landing distance, and other jumps kinematics contribute to the total forelimb kinematics picture during competition. Veterinarians and trainers should consider additional ways to decrease impact for canine athletes as they recover from injury. Dogs with previous agility-related injuries are 100.5 times more likely to experience another injury (27). It is important to note the concept of repetitive stress injury in these dogs. While based on our results there is no significant changes in peak force or peak contact pressure in dogs performing a single running bar jump, the role of repetitive forces on these agility dogs may be more of a significant contributor to injury risk. During the jump, first the shoulder is extending and the elbow is flexing to clear the obstacle and then these joint motions are reversed to prepare for landing (10). Based on a study evaluating muscular activation during jumping, the stride during jumping where the dog lifts off the ground to clear the obstacle and reaches forward with the forelimb to land was consistently the most demanding across forelimb muscles (28). Evaluating these parameters in terms of jump height may be beneficial for future recommendations in reducing bar jump associated injury.

Limitations of this study include the small test population, although it is comparable to other equine and canine studies on jump kinetics (5, 7, 8, 10, 14, 19, 20, 26, 29). In addition, this study also evaluated kinetics of only one breed, Border Collies, and previous studies have shown that breed can affect peak vertical forces as well as the percentages of weight borne on the forelimbs vs. the hind limbs (3, 29). Additional studies should include a wider range of breeds to determine whether there is variability between breeds for various jumping parameters. Because we attempted to control for velocity using set ground poles at specific distances, we chose to standardize dog breed and height to prevent confounding results. Future studies using this method will have to take into consideration optimal pole distance based on dog height and breed. Additionally, this study evaluated the kinetics of landing on the forelimbs of the dog in a setting using a single vertical jump with a straight-line approach. The type of obstacle and the distance between obstacles influences not only the peak vertical force, but also the landing angle, velocity, and jumping distance (5, 10). The agility course and the obstacles included are dependent on the sponsoring organization, venue size/layout, and the judge designing the course. This includes variations in spacing between obstacles, jump heights, and obstacle dimensions. Current research using bar jumps and agility dogs, including this study, evaluated only straight line approaches to the jumps. The control for velocity using ground poles with a set distance has influence on the dog's natural and preferred speed, which in turn can influence other kinetic and kinematic values. As most agility courses consist of multiple obstacles with varying degrees of turns and spacing between them, straight line jumps with set ground speeds do not fully represent jumping in true agility competitions. For example, in a typical standard agility course, at least 65% of the obstacles are jumps, which can be approached from multiple angles and speeds (28). Further studies are necessary to investigate changes in jump kinetics based on jump height in agility dogs approaching the jumps at different angles and preferred speeds. There are also other factors including jump style, fitness level, and handler experience that may have an effect on landing forces. Lastly, this study evaluated force utilizing a validated pressure sensitive walkway system as previously described. When attempting to compare data in the literature regarding magnitude of force values, the use of different gaiting systems should be considered. The magnitude of force values utilizing force plates and pressure sensitive walkways have been correlated, but direct comparisons are difficult to make. Studies comparing these data points in both dog and equine models have shown the peak vertical force was consistently lower for the pressure sensitive walkway when compared to the force plate system, and that these differences were greater when evaluated at a trot compared to a walk (30, 31). The authors note that this is important for future evaluation of canine jump kinetics and subsequent recommendations made from comparing the literature.

This study contributes to the current knowledge of canine jump kinetics that helps to inform decisions for training and competing in dog agility. Our data suggest that the single recommendation of decreasing jump height for older animals or injured animals in agility competitions might not significantly reduce impact on the forelimbs of these athletes. Additional studies will be needed to determine whether recommending a decrease in jump height in combination with other mitigating factors might lessen orthopedic insult to the forelimbs in the Border Collie and other agility athletes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was reviewed and approved by IACUC. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

JP assisted in study design, data collection, data evaluation, and writing the manuscript. NK and CZ assisted in study design, data evaluation, and writing the manuscript. NK also participated in data collection. CZ participated in study design, statistical analysis, and writing the manuscript. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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